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(54) Title: IN VIVO CTL ELICITATION BY HEAT SHOCK PROTEIN FUSION PROTEINS MAPS TO A DISCRETE ATP BINDING DOMAIN AND IS CD4<sup>+</sup> T CELL-INDEPENDENT

(57) Abstract: The present invention relates to a method of inducing a CD8<sup>+</sup> CTL response to a molecule in an individual deficient in CD4<sup>+</sup> T cells comprising administering to the individual an hsp or a portion of an ATP binding domain of an hsp joined to the molecule. In one embodiment, the present invention relates to a method of treating HIV in an individual deficient in CD4<sup>+</sup> T cells comprising administering to the individual an hsp or a portion of an ATP binding domain of an hsp joined to the molecule. Also encompassed by the present invention is a method of inducing a CD4<sup>+</sup> independent CTL response in an individual comprising administering to the individual a portion of an ATP binding domain of an hsp joined to the molecule. The present invention also relates to a method of inducing a CD8<sup>+</sup> CTL response in an individual comprising administering to the individual a portion of an ATP binding domain of an hsp joined to the molecule. In addition, the present invention relates to a composition characterized by a portion of an ATP binding domain of an hsp joined to a molecule.

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IN VIVO CTL ELICITATION BY HEAT SHOCK PROTEIN FUSION PROTEINS MAPS TO A DISCRETE ATP  
BINDING DOMAIN AND IS CD4<sup>+</sup> T CELL-INDEPENDENT

In Vivo CTL Elicitation by Heat Shock Protein Fusion Proteins Maps to a Discrete  
Domain and is CD4<sup>+</sup> T Cell-Independent

GOVERNMENT SUPPORT

The invention was supported, in part, by National Institutes of Health (NIH)  
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invention.

BACKGROUND OF THE INVENTION

When injected into an individual with diverse adjuvants, protein antigens  
10 usually stimulate the production of high-affinity IgG antibodies, indicating that they  
activate CD4 T helper cells, as well as B cells. These procedures generally fail,  
however, to elicit effective CD8 T cell responses. The reason, according to current  
views, is that the short peptides needed, in association with MHC class I molecules,  
to stimulate CD8 T cells arise from proteolytic cleavage of cytosolic proteins. Since  
15 injected protein antigens are generally unable to cross cellular lipid membranes, they  
fail to gain entry to the proper cytosolic "MHC class I processing pathway" and are  
thus unable to stimulate the production of CD8 T cells. Although there is evidence  
for alternative cellular pathways for processing some exogenous proteins to form  
peptide MHC class I complexes (Sigal, L.J., *et al.*, *Nature*, 398:77-80 (1999) and  
20 Gromme, M., *et al.*, *Proc. Natl. Acad. Sci. USA*, 96:10326-10331 (1999)) it remains  
generally true that protein antigens normally fail to stimulate significant CD8 CTL  
responses (Rock, K., *Today*, 17:131-137 (1996)).

There is now substantial evidence that heat shock proteins (hsps) isolated  
from tumors can be used as adjuvant-free anti-tumor vaccines in animals; hsp70 and  
25 the distantly related chaperones gp96 and calreticulin share this immunostimulatory

- activity (Udono, H. and Srivastava, P.K., *J. Exp. Med.*, 178:1391-1396 (1993); Udono, H., *et al.*, *Proc. Natl. Acad. Sci. USA*, 91:3077-3081 (1994); Suto, R. and Srivastava, P.K., *Science*, 269:1585-1588 (1995); Blanchere, N.E., *et al.*, *J. Exp. Med.*, 186:1315-1322 (1997); Tamura, Y., *et al.*, *Science*, 278:117-120 (1997) and
- 5 Nair, S., *et al.*, *J. Immunol.*, 162:6426-6432 (1999)). The fusion of large polypeptides (80-110 amino acids in length) to mycobacterial hsp70 (TBhsp70) creates potent immunogens that can elicit MHC class I-restricted, CD8<sup>+</sup> cytotoxic T cell responses sufficient to mediate rejection of tumors expressing the fusion partner (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)).
- 10 The means by which soluble hsp70 fusion proteins stimulate CD8 cytotoxic T cell (CTL) responses are unknown. Among the possible mechanisms are: 1) strong hsp-specific CD4<sup>+</sup> helper cell responses that enhance what might otherwise be a minimal response to the soluble proteins (Barrios, C., *et al.*, *Eur. J. Immunol.*, 22:1365-1372 (1992); Suzue, K. and Young, R.A., *J. Immunol.*, 156:873-876
- 15 (1996); Horwitz, M.S., *et al.*, *Nature Med.*, 4:781-785 (1998) and Könen-Waisman, S., *et al.*, *J. Infect. Dis.*, 179:403-413 (1999)); and 2) chaperone function of hsps delivers the fusion protein to intracellular compartments of antigen-presenting cells for processing into short peptides and loading onto MHC class I (Young, R.A., *Ann. Rev. Immunol.*, 8:401-420 (1990) and Schild, H., *et al.*, *Curr. Opinion Imm.*, 11:109-
- 20 113 (1999)). An understanding of the ability of hsp70 to stimulate CD8<sup>+</sup> CTL responses is needed to provide for more effective immunological prophylaxis and therapy for cancer and infectious diseases caused by intracellular pathogens.

## SUMMARY OF THE INVENTION

- The present invention is based on the discovery that a heat shock protein
- 25 (hsp; hsps are also known in the art as stress proteins), or a discrete domain thereof, that is joined to a heterologous molecule can produce a CD8<sup>+</sup> cytotoxic (cytolytic) lymphocyte (CTL) response in a host to which it is administered. The domain can be, for example, about half (*e.g.*, 40, 45, 50, 55, or 60%) of the adenosinetriphosphate (ATP) binding domain of an hsp. Moreover, the response is
- 30 independent of CD4<sup>+</sup> CTLs. Accordingly, the invention features compositions that include an hsp, or all or a portion of an hsp ATP binding domain, joined to a

heterologous molecule and methods of inducing a CD8<sup>+</sup> CTL response to a molecule in an individual (*e.g.*, a patient, such as a human patient, who has a deficiency of CD4<sup>+</sup> T cells) by administering that composition to the individual. The method can be used to treat a patient who has an acquired immune deficiency syndrome (AIDS) by, for example, administering to the patient an hsp, or a portion of an ATP binding domain of an hsp, that is joined to a molecule associated with a human immunodeficiency virus (HIV), such as an HIV antigen.

The invention has numerous advantages. For example, the compositions and methods described herein provide for highly effective CD8<sup>+</sup> CTL responses. These responses are useful in treating (*i.e.*, preventing or reducing the length or severity of symptoms associated with a disease process or preventing or attenuating the cellular events through which those symptoms are made manifest; treatment may be effective without completely eradicating all symptoms) diseases that are caused by or otherwise associated with intracellular pathogens. Diseases or conditions that are characterized by a deficiency (or complete lack of) CD4<sup>+</sup> T cells are particularly amenable to treatment.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1A is a graph of effector cell to target cell ratio (E:T) versus % specific lysis illustrating OVA-specific CTL elicited by immunization with OVA.TBhsp70 fusion protein without adjuvant in the splenocytes from wild-type C57/BL/6 mice.

Figure 1B is a graph of E:T versus % specific lysis illustrating OVA-specific CTL elicited by immunization with OVA.TBhsp70 fusion protein without adjuvant in the splenocytes from CD4<sup>+</sup> knockout mice (CD4<sup>-/-</sup> mice).

Figure 1C is a graph of E:T versus % specific lysis illustrating OVA-specific CTL elicited by immunization with OVA.TBhsp70 fusion protein without adjuvant in the splenocytes from mice which have very few CD8<sup>+</sup> T cells ( $\beta$ 2m<sup>-/-</sup> mice).

Figure 2A is a graph of E:T versus % specific lysis illustrating murine hsp70 fusion protein elicits CTL responses in wild-type C57BL/6 mice.

Figure 2B is a graph of E:T versus % specific lysis illustrating murine hsp70 fusion protein elicits CTL responses in CD4<sup>-/-</sup> mice.

Figure 3 is an illustration of the domains of the full length TBhsp70 which were separated into four segments I, II, III and IV and fused to C-terminal of OVA to make OVA.TBhsp70 fusion proteins; the numbers beneath each segment refer to the amino acid positions in TBhsp70.

5        Figure 4 is a graph of E:T versus % specific lysis illustrating OVA-specific T cell responses in mice immunized with OVA fused to domains of TBhsp70; splenocyte cultures from mice primed with OVA ( $\Delta$ ), OVA.TBhsp70 ( $\blacksquare$ ), OVA.TBhsp70 I ( $\nabla$ ), II ( $\blacklozenge$ ), III (X) and IV (+) were used as effector cells in the cytotoxicity assay.

10        Figure 5A is the P1 peptide amino acid sequence. When liberated from P1, SIYRYYYGL (SEQ ID NO: 1) (boldface) binds to K<sup>b</sup> to form the peptide-MHC complex recognized by the 2C TCR. In P1, SIYRYYYGL (SEQ ID NO: 1) is flanked 5' and 3' by sequences that lie immediately upstream and downstream, respectively, of peptide bonds that are cleaved (see arrows) in murine cells to liberate naturally  
15        occurring peptides (SIINFEEKL (SEQ ID NO: 2) from ovalbumin (Ova) and LSPFPFDL (SEQ ID NO: 3) from  $\alpha$ -ketoglutaraldehyde dehydrogenase ( $\alpha$ KG) (Falk, K., *et al.*, *Eur. J. Immunol.*, 22:1323-1326 (1992); Ukada, K., *et al.*, *J. Immunol.*, 157:670-678 (1996)).

20        Figure 5B is a diagram of the hsp65-P1 fusion protein, showing P1 at the C-terminus of hsp65.

Figure 5C are histograms which provide evidence that P1 and hsp65-P1 are processed intracellularly to yield the SYRGL (SEQ ID NO: 4) octapeptide. 48 hr after transfection with mammalian expression vectors (VR1055 and pCINeo), containing sequences that encode P1 and hsp65-P1, respectively, EL4 cells were  
25        incubated for 18 hr with an equal number of naive 2C T cells. Histograms show the percentage of live, 2C<sup>+</sup>CD8<sup>+</sup> cells that were stimulated to upregulate the activation marker CD69. The responses of these naive T cells to control EL4 cells, transfected with the empty (vector) plasmids, are shown as shaded histograms.

Figure 5D is a graph showing normal C57BL/6 mice have T cells that can  
30        recognize the SYRGL-K<sup>b</sup> complex. A CD8<sup>+</sup> T cell line, derived from C57BL/6 mice immunized with the SYRGL (SEQ ID NO: 4) peptide in adjuvant, specifically lysed

T2-K<sup>b</sup> target cells in a peptide-dependent manner. A highly cytolytic long-term cultured 2C CTL clone (L3.100) is shown for comparison.

Figure 6A is a graph showing CD8 CTL that recognize the SYRGL-K<sup>b</sup> complex are produced in C57BL/6 mice injected with hsp65-P1 in PBS but not in those injected similarly with equimolar amounts of various controls (a mixture of P1 and hsp65, the SYRGL (SEQ ID NO: 4) octapeptide, the P1 polypeptide itself, hsp65 itself).

Figure 6B is a graph showing SYRGL-specific CTL in mice injected with a various amounts of hsp65-P1, 0.015-1.5 nmoles (1-100µg) or a control fusion protein in which P1 is linked to the C-terminus of a maltose-binding protein (Mal-P1, 80µg); lysis of T2-K<sup>b</sup> target cells in the absence of added SYRGL (SEQ ID NO: 4) peptide is indicated by unfilled symbols.

Figure 6C are graphs showing depletion of CD8<sup>+</sup> T cells eliminates the SYRGL-specific CTL produced by mice injected with hsp65-P1. Lymph node and spleen cells from C57BL/6 mice immunized with 1.5 nmoles of hsp65 -P1 or Mal-P1 were cultured for 6 days and then depleted of CD8 T cells by magnetic sorting. The untreated, CD8-depleted, and CD8-enriched populations (30%, 1%, 90%, CD8<sup>+</sup> T cells respectively) were analyzed in a 4 hr cytolytic assay; lysis of T2-K<sup>b</sup> target cells in the absence of added SYRGL peptide is indicated by unfilled symbols.

Figure 7 is a graph showing <sup>51</sup>Cr-labeled splenic dendritic cells (spl dc), bone-marrow derived dendritic cells (bm-dc), or purified macrophages (mø), isolated from peritoneal lavage, all from B6 (H-2<sup>b</sup>) mice were incubated for 4 hr with a 2C CTL clone (L3.100: see Fig. 5D) and various concentrations of the SYRGL octapeptide. CTL target cell ratio (E:T)=5:1. Unfilled symbols show lysis when the control fusion protein (Mal-P1) was used in place of hsp65-P1.

Figure 8A illustrates that splenic dendritic cells and peritoneal lavage macrophages were purified by magnetic sorting and incubated for 18-24 hr with equimolar concentrations of hsp65-P1 or Mal-P1 before adding naive 2C T cells. Expression of the activation marker CD69, Hsp65-P1 or Mal-P1 were added to purified splenic dendritic cells, macrophages, or to media alone ("no APC") at 15nM (~1 µg/ml). After 24 hr, purified naive 2C T cells were added (T cell:APC ratio of 1:1), and 18 hr later cells were analyzed for CD69, gating on propidium iodide-

negative 2C<sup>+</sup>CD8<sup>+</sup> cells. The percentage of 2C T cells with increased expression of CD69<sup>+</sup> is indicated.

Figure 8B illustrates that splenic dendritic cells and peritoneal lavage macrophages were purified by magnetic sorting and incubated for 18-24 hr with  
5 equimolar concentrations of hsp65-P1 or unmodified hsp65 before adding naive 2C T cells. Dendritic cells or macrophages were incubated with hsp65-P1 or hsp65 before adding the naive 2C T cells and incubation was continued for an additional 18 hr (IL-2 assay) or 60 hr (proliferation assay) or 48 hr (IFN- $\gamma$  assay). "No Ag" means the dendritic cells and 2C T cells were present but hsp65-P1 and hsp65 were  
10 absent: "No T" cells means the hsp65-P1 was present but the 2C T cells were omitted.

Figure 8C is a graph illustrating inhibition of responses by a clonotypic monoclonal antibody to the 2C TCR (1B2). Bone marrow derived dendritic cells were incubated with 10 $\mu$ g/ml hsp65-P1 overnight. Equal numbers of naive 2C T  
15 cells were then added in the presence or absence of 1B2 Fab fragments (25 $\mu$ g/ml). After an additional 18 hr, cells and supernatants were analyzed, respectively, for CD69 expression (left panel) and IL-2 production (3H-thymidine incorporation by IL-2-responsive HT2 cells, right panel).

Figure 9A is a pair of graphs comparing dendritic cells' and macrophages' ability to stimulate T cell responses at limiting antigen dose in vitro. Fresh splenic  
20 dendritic cells or macrophages were incubated with various concentrations of hsp65-P1 or Mal-P1 fusion proteins for about 18 hr before adding purified naive 2C T cells (see Figs. 8A, 8B). Supernatants were sampled 18 hr later to determine IL-2 levels (upper panel). <sup>3</sup>H-thymidine was added at 48 hr and cells were harvested after an  
25 additional 18 hr to assess T cell proliferation (lower panel).

Figure 9B is a pair of graphs illustrating the behavior of hsp65 fusion protein-activated dendritic cells in vivo. Activation of dendritic cells in vivo. Myeloid dendritic cells from lymph nodes draining a subcutaneous site where hsp654-P1 was injected 24 hr previously show increased expression of MHC-1 (Kb)  
30 (lower panel) compared to myeloid dendritic cells from lymph nodes draining an uninjected site ("no treatment", upper panel).



Figure 9C is a trio of graphs illustrating the behavior of hsp65 fusion protein-activated dendritic cells in vivo. Dendritic cells activated with a noncognate hsp fusion protein (hsp65-NP) and pulsed with  $10^{-9}$  M SYRGL (SEQ ID NO: 4) peptide are more effective than nonactivated, similarly pulsed dendritic cells in stimulating naive T cells in vivo.  $8 \times 10^5$  dendritic cells were injected into a hind footpad of normal B6 mice that had been injected (iv) with  $2 \times 10^6$  naive 2C TCR+ cells (from 2C TCR transgenic mice RAG-deficient mice). 24 hrs after the footpad injection, 2C CD8<sup>+</sup> T cells in the draining popliteal lymph node were examined for CD69 expression. Frequency of CD69<sup>+</sup> 2C CD8<sup>+</sup> T cells in a lymph node draining the site where activated (control) dendritic cells (not pulsed with peptide) were injected (upper panel), or where SYRGL peptide-pulsed ( $1 \times 10^{-9}$  M) unactivated dendritic cells or activated dendritic cells were injected (middle panel and lower panel, respectively). Percentages of CD69<sup>+</sup> 2C cells are shown. Geometric means fluorescence values for MHC-1 (K<sup>b</sup>) on dendritic cells that had been incubated, prior to footpad injection, with or without hsp65-NP were 379 and 97, respectively.

Figure 10A is a pair of graphs of dendritic cell MHC class I expression plotted as a function of protein concentration of the added hsp fusion proteins and control proteins. Upper panel; dendritic cells from C57BL/6 mice. Lower panel; dendritic cells from C3H mice. Purified bone marrow derived dendritic cells were incubated for 24 hr with various concentrations of hsp65-P1 or other hsp65 fusion proteins, having as fusion partners influenza virus nucleoprotein (hsp65-NP) or human papilloma virus, type 16, E7 subunit (hsp65-E7 preparations #1 and #2) or with controls (hsp65 alone, P1 alone, E7 alone, an anti-TNP IgG antibody). MHC Class I protein levels on the dendritic cells were then determined by flow cytometry by gating on propidium iodide-negative CD11c<sup>+</sup> cells and using the Y3 antibody which recognizes both H-2<sup>b</sup> (K<sup>b</sup>) and H-2<sup>k</sup> MHC class I. MHC class I levels are shown as geometric mean fluorescence; the levels on untreated dendritic cells are represented by a dashed horizontal line.

Figure 10B is a pair of graphs of the dendritic cell MHC class I expression values from Figure 10A and are plotted as a function of endotoxin concentration (calculated from the endotoxin levels present in the added hsp fusion proteins and

other proteins). Upper panel; dendritic cells from C57BL/6 mice. Lower panel: dendritic cells from C3H mice.

Figure 10C is a graph showing that Hsp65-P1 stimulates production of CTL (anti-SYRGL) in CD4-deficient ( $CD4^{-/-}$ ) mice. As in Fig. 6A-6C the mice were  
5 injected s.c. twice, one wk apart, with 100 $\mu$ g of hsp65-P1 or Mal-P1 in PBS. One wk following the second injection, cells from spleen and draining lymph nodes were pooled and restimulated with 1 $\mu$ M SYRGL (SEQ ID NO: 4) peptide without addition of exogenous cytokines. Six days later the cells were used as effectors in a standard 4 hr cytolytic assay at various E:T ratios using  $^{51}$ Cr-labeled T2-K<sup>b</sup> cells as  
10 targets in the presence of 1 $\mu$ M SYRGL (SEQ ID NO: 4). Lysis of T2-K<sup>b</sup> cells in absence of SYRGL (SEQ ID NO: 4) is shown by unfilled symbols.

Figure 11 is the nucleotide (cDNA) (SEQ ID NO: 5) and amino acid (SEQ ID NO: 6) sequences of *Mycobacterium tuberculosis* hsp70 (TBhsp70) wherein segment II (nucleotides 481-1110; amino acids 161-370) is highlighted.

15 Figure 12 is the nucleotide (SEQ ID NO: 7) and amino acid (SEQ ID NO: 8) sequences of segment II of TBhsp70.

Figures 13A-13B are the nucleotide (SEQ ID NO: 9) and amino acid (SEQ ID NO: 10) sequences of murine hsp70 wherein segment II (nucleotides 568-1194; amino acids 190-398) is highlighted.

20 Figure 14 is the nucleotide (SEQ ID NO: 11) and amino acid (SEQ ID NO: 12) sequences of segment II of murine hsp70.

#### DETAILED DESCRIPTION OF THE INVENTION

An immunological response to a molecule that, notably, includes a CD8<sup>+</sup> CTL response, can be evoked in an individual by administering to that individual  
25 either an hsp joined to that molecule or a portion of an ATP binding domain of an hsp joined to that molecule (the molecule being virtually any biological substance, naturally- or nonnaturally-occurring with the exception of a portion of a stress protein). The CD8<sup>+</sup> CTL response can be evoked in an individual who has a deficiency of CD4<sup>+</sup> T cells (*i.e.* a CD4<sup>+</sup> T cell count considered by any routinely used  
30 medical standard to be physiologically abnormal). Physicians and others having ordinary skill in the art can identify such individuals, which include patients infected

with HIV. Accordingly, patients who are infected with HIV, or at risk of becoming so, can be treated with either an hsp joined to an HIV antigen (e.g., p24 or gp41) or a portion of an ATP binding domain of an hsp joined to an HIV antigen (e.g., p24 or gp41). Physicians and others having ordinary skill in the art can recognize and use  
5 other molecules associated with the HIV.

Heat shock proteins useful in the present invention are those that have an ATP binding domain and those that, when administered to an individual, induce a CD8<sup>+</sup> T cell response to a molecule to which they are joined. Full length hsps (e.g., hsp70 and hsp65) can be used, as can the ATP binding domains of hsps (or portions  
10 thereof). For example, the hsp moiety joined to the molecule can be the amino-terminal portion of the ATP binding domain. For example, the hsp moiety joined to the molecule can include or consist of about half of the ATP binding domain. For example, the hsp moiety can include or consist of about 25 to about 365 consecutive amino acid residues (e.g. 25-350, 50-300, 110-275, 125-250, 130-225, 135-200,  
15 150-200, 170-190, or 100-200 residues) of the ATP binding domain. More specifically, the hsp moiety can include or consist of amino acid residues 161-370 of *Mycobacterium tuberculosis* hsp70 or amino acid residues 190-398 of murine hsp70. Portions of hsp65 that are homologous to segment II of hsp70 (e.g. mycobacterial hsp65 such as *Mycobacterium bovis* BCG; mammalian hsp65, such as murine,  
20 canine, porcine, equine or human hsp65) can be used as described herein.

Those of ordinary skill in the art are well able to identify hsps and ATP binding domains within those proteins. Moreover, those artisans can make substitutions, if desired, in the sequences of these proteins or their domains that do not substantially reduce the abilities of those proteins or their domains to effectively  
25 induce CD8<sup>+</sup> T cell responses. Amino acid substitutions can be made on the basis of similarity in polarity, charge, solubility, hydrophobicity, hydrophilicity, or the amphipathic nature of the residues involved. For example, the nonpolar (hydrophobic) amino acid residues alanine, leucine, isoleucine, valine, proline, phenylalanine, tryptophan, and methionine can be substituted one for another; polar  
30 neutral amino acid residues such as glycine, serine, threonine, cysteine, tyrosine, asparagine, and glutamine can be substituted one for another; positively charged (basic) amino acid residues such as arginine, lysine, and histidine can be substituted

one for another; and negatively charged (acidic) amino acid residues such as aspartic acid and glutamic acid can be substituted one for another. For example, the hsp moiety used as described herein can include 1-25% conservative amino acid substitutions.

5 Any hsp or any portion of the hsp ATP binding domain can be purified from natural sources, recombinantly produced, or chemically synthesized. For example, an hsp or a portion thereof can be obtained from mycobacteria (*e.g.*, *Mycobacterium tuberculosis*, *Mycobacterium bovis*, *Mycobacterium leprae*, or *Mycobacterium smegmatis*), mammals (*e.g.* a murine, canine, porcine, equine, or human), fungi, 10 parasite, or bacteria. Methods for recombinantly producing hsps or portions thereof are also well known (production in bacteria such as *E. coli*) are described herein. In addition, the hsp or the portion thereof can be obtained from a commercial supplier.

Molecules useful in the present methods include any molecule against which a CD4<sup>+</sup> independent immune response is desired. A "molecule" includes, but is not 15 limited to, proteins or fragments thereof (*e.g.*, proteolytic fragments), peptides (*e.g.*, synthetic peptides or polypeptides), antigens, glycoproteins, carbohydrates (*e.g.*, polysaccharides and oligosaccharides), lipids, glycolipids, DNA (*e.g.*, recombinant DNA), killed or attenuated whole organisms (*e.g.*, viruses, bacteria, mycobacteria, parasites or fungi) or portions thereof, toxins, toxoids or any other organic molecule.

20 Molecules useful in the present methods can be obtained from a variety of sources using techniques routinely practiced in the art. For example, the molecule can be obtained from pathogens or organisms such as bacteria, mycobacteria, viruses, fungi or parasites. While the molecule can be isolated (*e.g.*, purified or partially purified (*e.g.* physically separated from at least 50% of the biological 25 substances with which it naturally associates), it can also be chemically synthesized, recombinantly produced, or purchased from a commercial supplier.

The hsp or portion thereof is "joined" to a molecule against which an immune response is desired. The term "joined" includes covalent attachment of the hsp, or a portion thereof, to the molecule. The conjugation can be carried out using 30 techniques routinely practiced in the art (*e.g.*, by forming a covalent bond between the hsp, or the portion thereof, and the molecule or by reductive amination). The term "joined" also includes fused proteins, such as those created by recombinant

techniques or chemical synthesis. The fusion protein can include the molecule fused to the amino-terminal region or the C-terminal region of the hsp, or the portion thereof.

The CD8<sup>+</sup> CTL responses induced by the methods of the present invention  
5 can be used for prophylaxis and/or therapy of diseases or conditions, particularly those characterized by a lack or deficiency of CD4<sup>+</sup> T cells. That is, the hsp or portion thereof joined to the molecule against which an immune response is desired can be administered to an individual either before or after a disease or condition is manifested and can result in prevention, amelioration, elimination or delay in the  
10 onset or progression of the disease state. For example, the present invention can be used to prevent or treat an individual positive for human immunodeficiency virus (HIV) and the opportunistic infections associated with HIV. In one embodiment, the HIV positive individual is deficient in CD4<sup>+</sup> T cells.

In the methods of the present invention, an effective amount of the hsp or  
15 portion thereof joined to the molecule against which an immune response is desired is administered to an individual (e.g., mammal such as human). As used herein an "effective amount" is an amount that induces a CD4<sup>+</sup> T cell independent immune response to the molecule in an individual. In a particular embodiment, an "effective amount" is an amount such that when administered to an individual, it results in an  
20 enhanced CD8<sup>+</sup> CTL response to the molecule relative to the CD8<sup>+</sup> CTL response to the molecule in an individual to whom an effective amount was not administered. For example, an effective amount or dosage of the hsp or portion thereof joined to the molecule against which an immune response is desired is in the range of about 50 pmoles to about 5000pmole. In one embodiment, the dosage range is from about  
25 80pmole to about 3500pmoles; in another embodiment, the dosage range is from about 100pmoles to about 2000pmoles; and in a further embodiment the dosage range is from about 120pmoles to about 1000pmoles. The appropriate dosage of hsp or portion thereof joined to the molecule against which an immune response is desired for each individual will be determined by taking into consideration, for  
30 example, the particular hsp and/or molecule being administered, the type of individual to whom the composition is being administered, the age and size of the individual, the condition or disease being treated or prevented and the severity of the

condition or disease. Those skilled in the art will be able to determine using no more than routine experimentation the appropriate dosage to administer to an individual.

The hsp or portion thereof joined to the molecule against which the immune response is desired can be administered to the individual in a variety of ways. The routes include intradermal, transdermal, (e.g., slow release polymers), intramuscular, intraperitoneal, intravenous, subcutaneous, oral, epidural and intranasal routes. Any other convenient route of administration can be used, for example, infusion or bolus injection, infusion of multiple injections over time, or absorption through epithelial or mucocutaneous linings. In addition, the hsp joined to the molecule can be administered with other components or biologically active agents, such as adjuvants, pharmaceutically acceptable surfactants (e.g., glycerides), excipients, (e.g., lactose), liposomes, carriers, diluents and vehicles.

Further, in the embodiment in which the molecule is a protein (peptide), the hsp or portion thereof joined to the molecule can be administered by *in vivo* expression of polynucleotides encoding such into an individual. For example, the hsp or portion thereof and/or the molecule can be administered to an individual using a vector, wherein the vector which includes the hsp or portion thereof joined to the molecule is administered under conditions in which the hsp or portion thereof and the molecule are expressed *in vivo*.

Several expression system vectors that can be used are available commercially or can be produced according to recombinant DNA and cell culture techniques. For example, vector systems such as yeast or vaccinia virus expression systems, or virus vectors can be used in the methods and compositions of the present invention (Kaufman, R.J., *J. Meth. Cell and Molec. Biol.*, 2:221-236 (1990)). Other techniques using naked plasmids or DNA, and cloned genes encapsulated in targeted liopsomes or in erythrocyte ghosts can be used to introduce the hsp or portion joined to the molecule into the host (Friedman, T., *Science*, 244:1275-1281 (1991); Rabinovich, N.R., *et al.*, *Science*, 265:1410-1404 (1994)). The construction of expression vectors and the transfer of vectors and nucleic acids into various host cells can be accomplished using genetic engineering techniques, as described in manuals like *Molecular Cloning* and *Current Protocols in Molecular Biology*, which

are incorporated by reference, or by using commercially available kits (Sambrook, J. *et al.*, *Molecular Cloning*, Cold Spring Harbor Press, 1989; Ausubel, F.M., *et al.*, *Current Protocols in Molecular Biology*, Greene Publishing Associates and Wiley-Interscience, 1989).

5 As demonstrated in Example 1, hsp70 fusion proteins elicit CD8<sup>+</sup> CTL in the absence of CD4<sup>+</sup> T lymphocytes and this function resides in a 200-amino acid segment of TBhsp70, indicating that chaperone activity is not required. To gain insights into the mechanisms by which soluble hsp fusions can elicit CD8<sup>+</sup> CTL against the fusion partner, hsp70 was dissected to ascertain whether a particular hsp domain is necessary, and knockout mice were used to determine whether the fusion protein's immunogenicity is dependent on CD4<sup>+</sup> T lymphocytes. It was found that the ability to elicit CD8<sup>+</sup> CTL depends on a discrete 200-amino acid protein domain, indicating that the fusion protein's immunogenicity for CD8<sup>+</sup> T cells does not require coupled chaperone function or peptide binding. Further, it was found that 10 ovalbumin.hsp70 fusion protein elicited anti-ovalbumin CD8<sup>+</sup> CTL about equally well in CD4 knockout and wild-type C57BL/6 mice, and also when the hsp70 was of mycobacterial (*Mycobacterium tuberculosis*) or murine (self) origin. The ability of hsp70 fusion proteins to elicit CD4-independent CTL responses indicates that hsp70 fusion proteins can be used for immunological prophylaxis and therapy against 15 disease in CD4<sup>+</sup> T cell deficient individuals.

As demonstrated in Example 2, a mycobacterial heat shock protein, 65kDa (hsp65), fused to a polypeptide (P1) that contains an octapeptide (SIYRYYGL (SEQ ID NO: 1)) agonist for a particular T cell receptor (2C TCR) stimulated C57BL/6 mice, as well as CD4-deficient mice, to produce CD8<sup>+</sup> cytolytic T lymphocytes 25 (CTL) to the fusion partner's octapeptide. This and other hsp65 fusion proteins, but not native hsp65 itself, stimulated dendritic cells, in vitro and in vivo, to upregulate the levels of MHC (class I and II) and costimulatory (B7.2) molecules. The results provide a mechanism for the general finding that hsp fusion proteins, having fusion partners of widely differing lengths and sequences, elicit CD8 CTL to peptides from 30 the fusion partners, without requiring exogenous adjuvants or the participation of CD4<sup>+</sup> T cells.

When mycobacterial hsp fused with large protein fragments, termed fusion partners, are injected into mice in saline solution (PBS) without added adjuvants several of them were previously shown to stimulate the production of CD8 CTL that recognize short peptide epitopes (8-10 amino acids in length) that arose from the fusion partners. The fusion partners varied from about 80 to 110 amino acids in length and were derived from ovalbumin (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)), influenza virus nucleoprotein (Anthony, L., *et al.*, *Vaccine*, 17:373-383 (1999)), and an entire protein subunit of a human papilloma virus (N.R. Chu, personal communication). As described in Example 2, to explore the mechanisms that permit these hsp to be effective with such diverse fusion partners, and that enable the hsp fusion proteins to serve as effective immunogens for CD8 T cells without requiring adjuvants, the immunogenic activities of fusion proteins prepared from the 65 kDa hsp from *Mycobacterium bovis*, BCG strain (here called hsp65) were studied.

The principal fusion partner used in Example 2 was a polypeptide that contains an octapeptide sequence, SIYRYYGL (SEQ ID NO: 1) (hereafter called SYRGL (SEQ ID NO: 4), Udaka, K., *et al.*, *Cell*, 69:989-998 (1992)), which together with K<sup>b</sup> serves as a potent stimulator of CD8 T cells having the TCR of a CTL clone called 2C (Kranz, D., *et al.*, *Proc. Natl. Acad. Sci. USA*, 81:573-577 (1984)). This peptide was identified in a synthetic peptide library and, so far as is known, does not occur in nature. The use of various T cells that express the 2C TCR, particularly naive 2C T cells (Cho, B., *et al.*, *Proc. Natl. Acad. Sci. USA*, 96:2976-2981 (1999)), were relied on as specific probes to obtain evidence that i) dendritic cells are more effective than macrophages in presenting the processed hsp fusion protein to naive CD8 T cells, ii) dendritic cells are stimulated directly by each of several hsp65 fusion proteins tested, but not by "native" hsp65 itself, to increase surface expression of MHC class I and II and costimulatory (B7.2) molecules, and iii) CD4 T cells are not required for the fusion protein's ability to elicit production of CD8 CTL *in vivo*. Taken together, the results described herein indicate that diverse soluble heat shock fusion proteins, regardless of the length or sequence of the fusion partners, stimulate CD8 T cell responses to peptides derived from the fusion partners without requiring exogenous adjuvants. The findings are of particular interest in



view of the need to develop protective vaccines against intracellular pathogens for which current immunization strategies are inadequate (e.g., against HIV-1, human papilloma virus, various herpes viruses, malaria).

## EXEMPLIFICATION

### 5 Example 1 *In Vivo* CTL Elicitation by hsp70 Fusion Proteins Maps to a Discrete Domain and is CD4<sup>+</sup> T Cell-Independent

#### Materials and Methods

#### Expression vectors:

All constructs used to produce OVA.hsp70 fusion proteins were made in the  
10 bacterial expression plasmid pKS11h (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)). Fusion constructs, consisting of OVA fused to the N-terminus of various segments of hsp70, were inserted downstream of the histidine tag sequence. A portion of ovalbumin (amino acid 230-359, hereafter referred to as OVA) was amplified from pOV230 (McReynolds, L.A., *et al.*, *Gene*, 2:217-231  
15 (1977)) by PCR using upstream primer oQH025 and the downstream primer oQH027. Functional and structural domains of TBhsp70 based on crystal structures of ATP domain of bovine hsc70 (Flaherty, K.M., *et al.*, *Nature*, 346:623-628 (1990)) and peptide-binding domain of *E. coli* DnaK (Zhu, X., *et al.*, *Science*, 272:1606-1614 (1996)) were used. The full-length TBhsp70 were separated into four  
20 segments I, II, III and IV. The full-length TBhsp70 and each segment were fused to C-terminal of OVA to make OVA.TBhsp70 fusion proteins. (The sequences of these and other PCR primers are listed at the end of the Methods and Materials section).

The OVA expression vector pQH07 was constructed by subcloning OVA  
25 into the NdeI and NheI sites of pKS11h. Full-length TBhsp70 and four truncated TBhsp70 segments I (aa 1-166), II (aa 161-370), III (aa 360-517) and IV (aa 510-625) were amplified from plasmid pY3111/8 (kind gift of W. Wu, StressGen Biotechnologies, Vancouver Canada). The upstream primer for full-length TBhsp70 and segment I is oQH001, and the downstream primers are oJR061 and oQH011,  
30 respectively. The upstream primers for TBhsp70 II, III and IV are oQH012, oQH014 and oQH106, respectively. The downstream primers are oQH013, oQH015 and

oJR061, respectively. The plasmids pQH06, pQH08, pQH09, pQH10 and pQH11, which express OVA fused to TBhsp70, TBhsp70 segment I, segment II, segment III and segment IV respectively, were constructed by subcloning the full-length and truncated TBhsp70 PCR products into the BamHI and EcoRI sites of pQH07 (at the C-terminus of OVA). Murine hsp70.1 coding sequence (referred to here as mhsp70) was amplified from plasmid pmhsp70.1 by PCR using the upstream primer oJR102 and the downstream primer oJR103. Plasmid pQH12, expressing OVA.mhsp70 fusion protein, was created by subcloning mhsp70 into the BamHI and EcoRI sites of pQH07. All plasmids were verified by sequencing in both directions with double-stranded DNA templates.

#### Recombinant protein purification:

OVA, OVA.TBhsp70, OVA.TBhsp70 II, OVA.TBhsp70 III, and OVA.TBhsp70 IV were induced in *E. coli* (BL21(DE3)pLysS) for 9 hours at 25° in the presence of 0.5-1 mM isopropyl thiogalactoside (IPTG) and were purified as soluble proteins. The mycobacterial segment I and murine hsp70 fusion proteins were induced in *E. coli* for 4 hours at 37° with 1 mM IPTG and purified from inclusion bodies and then refolded as previously described (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997) and Suzue, K. and Young, R.A., *J. Immunol.*, 156:873-876 (1996)). All proteins were purified using nitrilo-triacetic acid Ni<sup>2+</sup> column (Qiagen, Hilden Germany) and HiTrap-Q anion exchange chromatography (Pharmacia, Piscataway, NJ) as previously described (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997) and Suzue, K. and Young, R.A., *J. Immunol.*, 156:873-876 (1996)). Purity was assessed using 4-20% gradient SDS-PAGE gels stained with Coomassie Blue (Bio-Rad, Hercules CA). All proteins were dialyzed against phosphate-buffered saline (PBS), and sterile filtered at 0.2µM. Protein concentrations were measured by Lowry assay (Bio-Rad) and expressed in molar terms to allow simple comparison of proteins of differing molecular weights.

#### Mice and immunizations:

Six- to eight-week old female C57BL/6, CD4<sup>-/-</sup> and β2m<sup>-/-</sup> mice were obtained from the Jackson Laboratory (Bar Harbor, ME) and Taconic Farms

(Germantown, NY). Both knockout mice have C57BL/6 (H-2<sup>b</sup>) genetic backgrounds. Groups of 3 to 4 mice were injected intraperitoneally (i.p.) with 120 pmoles of recombinant protein in PBS; a second injection was performed subcutaneously (s.c.) two weeks later. The mice were sacrificed 10 days after the  
5 boost and splenocytes within groups were pooled (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)).

#### Cell line:

EG7-OVA cells were cultured as previously described (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)). OVA-specific CTL elicited by  
10 immunization with OVA.TBhsp70 fusion protein without adjuvant were examined. The splenocytes from mice immunized with OVA ( $\Delta$ ) or OVA.TBhsp70 ( $\blacksquare$ ) were incubated with irradiated EG7-OVA cells for 6 days in the absence of added cytokines and then used as effector cells (E) in a standard 4 hour cytotoxicity assay. The <sup>51</sup>Cr-labeled target cells (T) were: T2-K<sup>b</sup> (dashed line) and T2-K<sup>b</sup>-pulsed with  
15 SIINFEKL peptide (SEQ ID NO: 2) (solid line) at 33  $\mu$ g/ml. Splenocytes from wild-type C57/BL/6 mice are shown in Figure 1A; splenocytes from CD4 <sup>-/-</sup> mice are shown in Figure 1B; and splenocytes from  $\beta$ 2m <sup>-/-</sup> mice are shown in Figure 1C.

#### CTL assays:

CTL assays were performed as described (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997)). Splenocyte cultures from mice primed with OVA  
20 ( $\Delta$ ), OVA.TBhsp70 ( $\blacksquare$ ), OVA.TBhsp70 I ( $\nabla$ ), II ( $\blacklozenge$ ), III (X) and IV (+) were used as effector cells in the cytotoxicity assay (See Figure 4). Results shown are representative of experiments repeated two to five times.

#### PCR primers:

25 oQH025 (5'- GCAGTACTCATATGATCCTGGAGCTTCCATTG  
CCAGTGGGACAATG-3') (SEQ ID NO: 13)

oQH027 (5'- CTCCGACCTCACCTACGACGTTTCGCAGAGACTTC  
TTAAAATTATCCGATCGCCTAGACCTAGT-3') (SEQ ID NO: 14)

oQH001 (5'- ATAGTACTGGATCCATGGCTCGTGCGGTCGGGATC  
GACCTCGGG- 3') (SEQ ID NO: 15)

oJR061 (5'- GGAATTCCTATCTAGTCACTTGCCCTCCCGGCCGTC-3') (SEQ  
ID NO: 16)

5 oQH011 (5'- GTCGACGAATTCATCATCAGATTCGCTGCTCCTTCTCGCCC  
TTGTCGAG-3') (SEQ ID NO: 17)

oQH012 (5'- GTCGACGGATCCATGGAGAAGGAGCAGCGAATCCTGGT  
CTTCGACTTG-3') (SEQ ID NO: 18)

oQH014 (5'-  
10 GTCGACGGATCCATGGTGAAAGACGTTCTGCTGCTTGATGTTACCCCG-3')  
(SEQ ID NO: 19)

oQH016 (5'- GTCGACGGATCCATGCGTAATCAAGCCGAGACATTGGTCTA  
CCAGACG-3') (SEQ ID NO: 20)

oQH013 (5'-GTCGACGAATTCATCACGGGGTAACATCAAGCAGCAGAA  
15 CGTCTTTCAC-3') (SEQ ID NO: 21)

oQH015 (5'-GTCGACGAATTCATCAGACCAATGTCTCGGCTTGATTACG  
AACATCGGC-3') (SEQ ID NO:22)

oJR102 (5'-TCTAGAGGATCCATGGCCAAGAACACGGCGATC-3') (SEQ ID  
NO: 23)

20 oJR103 (5'-TCTAGAGAATTCCTAATCCACCTCCTCGATGGTGGGTCC-3')  
(SEQ ID NO:24)

Previous studies demonstrated that soluble, adjuvant-free TBhsp70 fusion proteins elicit substantial immune responses, including CD8<sup>+</sup> CTLs, in mice (Suzue, K., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:13146-13151 (1997) and Suzue, K. and Young, R.A., *J. Immunol.*, 156:873-876 (1996)). The basis for the effectiveness of hsp70 fusions is unclear as most soluble proteins do not elicit significant CD8<sup>+</sup> T cell responses (reviewed in Braciale, T.J., *et al.*, *Immunol. Rev.*, 98:95-114 (1987); Jondal, M., *et al.*, *Immunity*, 5:295-302 (1996)). While there is evidence that the hsp moiety of mycobacterial hsp fusion proteins acts as an effective carrier in the classic sense, enhancing B cell responses to chemically conjugated pneumococcal polysaccharides (Könen-Waisman, S., *et al.*, *J. Infect. Dis.*, 179:403-413 (1999)) and malarial polypeptide (Barrios, C., *et al.*, *Eur. J. Immunol.*, 22:1365-1372 (1992)), carriers are not known to stimulate CTL production. It was reasonable to expect that hsp70 fusion proteins provide hsp70-specific cognate CD4<sup>+</sup> T cell help to OVA-specific CD8<sup>+</sup> CTL by activating shared professional antigen presenting cells (APCs) as suggested by many, and demonstrated recently (Bennett, S.R.M., *et al.*, *Nature*, 393:478-480 (1998); Ridge, J.P., *et al.*, *Nature*, 393:474-478 (1998) and Schoenberger, S.P., *et al.*, *Nature*, 393:480-483 (1998)).

As described herein, this cognate help hypothesis was tested using CD4 deficient (knockout) mice (CD4<sup>-/-</sup>). Wild-type C57BL/6, CD4<sup>-/-</sup>, and  $\beta$ 2m<sup>-/-</sup> mice were each immunized with OVA or OVA.TBhsp70 fusion protein. As expected, immunization of wild-type mice with OVA.TBhsp70, but not OVA, generated CTL specific for the immunodominant epitope of OVA (SIINFEKL) (Figure 1A). The same results were obtained when the CD4<sup>-/-</sup> mice were immunized with OVA.TBhsp70 (Figure 1B).  $\beta$ 2m<sup>-/-</sup> mice, which have very few CD8<sup>+</sup> T cells, did not develop OVA-specific CTL after immunization with OVA.TBhsp70 or with OVA alone (Figure 1C).

Previous efforts to determine whether CD4<sup>+</sup> T cell help is necessary for generation of CD8<sup>+</sup> CTL have drawn differing conclusions. CD4 knockout mice exhibit a range of CD8<sup>+</sup> CTL responses: CD4-dependent, weakly dependent, or independent. CTL responses to minor histocompatibility antigens (Ridge, J.P., *et al.*, *Nature*, 393:474-478 (1998), Guerder, S. and Matzinger, P., *J. Exp. Med.*, 176:553-564 (1992)) or to ovalbumin loaded into spleen cells (Bennett, S.R.M., *et*

*al.*, *J. Exp. Med.*, 186:65-70 (1997)) are CD4<sup>+</sup> dependent. Some potent CD8<sup>+</sup> T cell immunogens including viruses (Bachmann, M.F., *et al.*, *J. Immunol.*, 161:5791-5794 (1988)), such as lymphocytic choriomeningitis virus (Leist, T.P., *et al.*, *J. Immunol.*, 138:2278-2281 (1987); Ahmed, R., *et al.*, *J. Virol.*, 62:2102-2106 (1988);

- 5 Rahemtulla, A., *et al.*, *Nature*, 353:180-184 (1991) and von Herrath, M., *et al.*, *J. Virol.*, 70:1072-1079 (1996)), ectromelia virus (Buller, R.M., *et al.*, *Nature*, 328:77-79 (1987)) and some influenza virus subtypes (Wu, Y. and Liu, Y., *Curr. Biol.*, 4:499-505 (1994)), as well as allogeneic cells (Krieger, N.R., *et al.*, *J. Exp. Med.*, 184:2013-2018 (1996)) elicit strong CD8<sup>+</sup> T cell responses in wild-type and CD4<sup>-/-</sup> mice. The similarity of CD8 CTL responses to OVA.TBhsp70 in CD4<sup>-/-</sup> and wild-type mice suggests that hsp70 fusion proteins are relatively potent CD8<sup>+</sup> CTL immunogens. A similar result, showing that CD4<sup>+</sup> T cells are not required for the CD8<sup>+</sup> CTL response elicited by another mycobacterial heat shock fusion protein (hsp65 fused to a polypeptide containing an epitope for 2C CD8<sup>+</sup> T cells) using
- 10 CD4<sup>-/-</sup> mice is described in Example 2. In addition, the ability of a non-homologous hsp, gp96, to elicit tumor rejection requires CD4<sup>+</sup> T cells at tumor challenge, but not during priming with tumor-derived gp96 (Udono, H. and Srivastava, P.K., *Proc. Natl. Acad. Sci. USA*, 91:3077-3081 (1994)).
- 15

It has been proposed that the immunostimulatory effects of certain hsp fusion proteins may be due to the bacterial origin of the hsp moiety (Schild, H., *et al.*, *Curr. Opinon Imm.*, 11:109-113 (1999)). This possibility was examined by making OVA.hsp70 fusion proteins with the murine homologue of TBhsp70 (Hunt, C. and Calderwood, S., *Gene*, 87:199-204 (1990)), here referred to as mhsp70. Immunization of wild-type C57BL/6 mice with OVA.mhsp70, but not OVA, elicited

20 CTL responses equivalent to those generated by the TBhsp70 fusion protein (Figure 2A). The response to OVA.mhsp70 was also independent of CD4 (Figure 2B). Since a CD4<sup>+</sup> T cell response to self (murine) hsp70 is unlikely, the effectiveness of the murine hsp70 fusion protein is in accord with the more direct evidence for CD4-independence obtained using CD4<sup>-/-</sup> mice (see above).

25

30 The ability of hsp fusion proteins to elicit CTLs against the fusion partner may be a consequence of the hsp moieties' chaperone activity, assuming that this activity is preserved in the fusion protein. To investigate this issue, TBhsp70 was

divided into four linear segments and OVA and a glycine/serine linker were fused to the amino-terminus of each segment, creating OVA.TBhsp70s I-IV (Figure 3). Each segment corresponds to a distinct structural domain of hsp70 as described by Flaherty, K.M., *et al.*, *Nature*, 346:623-628 (1990) and Zhu, X., *et al.*, *Science*, 272:1606-1614 (1996). As shown in Figure 3A, the amino-terminal ATP-binding domain was divided into its two structural lobes: I (aa 1-160) and II (aa 161-362). The carboxy-terminal peptide-binding domain was divided into a  $\beta$ -sandwich domain, III (aa 364-512), and an  $\alpha$ -helical domain, IV (aa 512-625).

Six groups of three C57BL/6 mice were immunized with 120 pmoles of OVA, OVA.TBhsp70, and OVA fused to segments I, II, III and IV. CTL assays showed that splenocytes from mice immunized with OVA.TBhsp70 and OVA fused to segment II lysed T2-K<sup>b</sup> cells in the presence, but not absence, of the OVA K<sup>b</sup> epitope, SIINFELK (Figure 4). In contrast, cells from mice immunized with OVA and OVA fused to segments I, III and IV were ineffective, even at an E:T ratio of 80:1. Levels of cytolysis obtained with splenocytes from mice immunized with OVA.TBhsp70 and OVA fused to segment II were indistinguishable (Figure 4). These results show that half of the ATP-binding domain of TBhsp70 (aa 161-362) is sufficient to stimulate substantial production of anti-OVA CTL response in the absence of adjuvant.

Since it is highly unlikely that segment II preserves chaperone activity we conclude that the ability of the fusion proteins to elicit CD8<sup>+</sup> T cell does not depend on the hsp moieties' chaperone properties. The data described herein support a model in which hsp70 bypasses the need for CD4<sup>+</sup> help by directly or indirectly activating or affecting the maturation state of APCs such as dendritic cells in a manner similar to some viruses (Ruedl, C., *et al.*, *J. Exp. Med.*, 189:1875-1883 (1999)). According to this model, hsp70 fusion proteins likely activate few CD8<sup>+</sup> T cells to release immunostimulatory cytokines in draining lymph nodes. These cytokines, in turn, provide the help required to upregulate expression of costimulatory molecules on APCs in the lymph node, leading to further CD8<sup>+</sup> T cell activation (Ruedl, C., *et al.*, *J. Exp. Med.*, 189:1875-1883 (1999)). Recent studies demonstrate that exposure of macrophages to bacterial and human hsp60 (Chen, W., *et al.*, *J. Immunol.*, 162:3212-3210 (1999); Kol, A., *et al.*, *J. Clin. Invest.* 103:571-

577 (1990)), murine hsp70 and gp96 (Suto, R. and Srivastava, P.K., *Science*, 269:1585-1588 (1995); Breloer, M., *et al.*, *J. Immunol.*, 162:3141-3147 (1999)) increases expression of adhesion molecules and cytokines.

The ability to hsp70 fusion proteins to elicit CTL responses in the absence of CD4<sup>+</sup> cells indicates that hsp70 can be used as a vehicle for the development of prophylaxis and therapy of diseases or conditions characterized by a lack or deficiency of CD4<sup>+</sup> cells, such as HIV-1 and its opportunistic infections. Infections by HIV and its simian cousin SIV can lead to a substantial reduction of CD4<sup>+</sup> T cells, thereby crippling the host's immune response to HIV and other pathogens. This loss of CD4<sup>+</sup> cells is thought to impair the development and maintenance of CD8<sup>+</sup> CTL responses (Kalams, S.A., *et al.*, *J. Virol.*, 73:6715-6720 (1999)). Recent studies conclude that strong HIV-specific CTL responses are required to keep HIV-1 infection in check and to destroy HIV-infected cells (Harrer, T., *et al.*, *AIDS Res. Hum. Retro.*, 12:585-592 (1996); Harrer, T., *et al.*, *J. Immunol.*, 156:2616-2623 (1996); Yang, O.O., *et al.*, *J. Virol.*, 70:5799-5806 (1996); Yang, O.O., *et al.*, *J. Virol.*, 71:3120-3128 (1997); Matano, T., *et al.*, *J. Virol.*, 72:164-169 (1998) and Wagner, L., *et al.*, *Nature*, 391:908-911 (1998)).

Example 2      Heat Shock Fusion Proteins Stimulate Dendritic Cells and Elicit  
Production of Cytolytic T Lymphocytes Without Requiring  
Participation of CD4 T Cells

Methods and Materials

Mice, CTL clones and cell lines

C57BL/6 (H-2<sup>b</sup>), Cd4-deficient (CD4 tm1Mak; H-2<sup>b</sup>), and C3H/HeJ mice (H-2<sup>k</sup>) were obtained from The Jackson Laboratories (Bar Harbor, ME), maintained in barrier cages under specific pathogen free conditions, and immunized between 4- and 10-weeks of age. 2C TCR transgenic mice (H-2<sup>b</sup>) contain the rearranged transgenes encoding the  $\alpha\beta$  TCR from a 2C CTL clone (Sha, W., *et al.*, *Nature*, 335:271-274 (1988)). 2C TCR transgenic mice deficient for the recombination activating gene-1 (termed 2C/RAG) (Manning, T., *et al.*, *J. Immunol.*, 159:4665-4675 (1997)) were used as a source of naive T cells for in vitro assays (Cho, B., *et al.*, *Proc. Natl. Acad. Sci. USA*, 96:2976-2981 (1999)). 2C CTL clone: L3.100, has



been previously described (Sykulev, Y., et al., *Immunity*, 9:475-483 (1998)). EL4 cells were obtained from the ATCC (Rockville, MD) and T2-K<sup>b</sup> cells were a generous gift from Peter Creswell, Yale University.

#### Plasmids, peptides, and proteins

- 5 In the P1 polypeptide the sequences flanking the – and C- termini of the SYRGL octapeptide (Fig. 5A), from ovalbumin (ova251-257) and  $\alpha$ -ketoglutaraldehyde dehydrogenase, respectively, were modified by addition of a lysine residue penultimate to the N-terminus (out of ubiquitination consideration) (Eisenlohr, L., et al., *J. Exp. Med.*, 175:481-487 (1992); York, I.A. and Rock, K.L.,  
10 *Annu. Rev. Immunol.*, 14:369-396 (1996)), and an isoleucine and a tyrosine residue were added at the – and C-termini for cloning purposes. Complementary oligonucleotides encoding P1 were synthesized and cloned into a mammalian expression vector VR1055 (Vical, San Diego, CA), and subsequently subcloned as an in-frame fusion at the 3' end of *M. bovis* BCG hsp65 gene (hsp65-P1) into the  
15 bacterial expression vector pET28A+ (Novagen, Madison, WI). The P1 sequence was also subcloned into the 3' end of the gene encoding *E. coli* maltose binding protein in pMAL-p2, using the pMAL protein fusion system (New England Biolabs, Beverly, MA), as well as into the mammalian expression vector pCIneo (Promega, Madison, WI). All hsp65 fusion proteins used in this example, as well as the  
20 unmodified hsp65, were produced as recombinant proteins in *E. coli*. They were purified under denaturing conditions from the soluble fraction of bacterial lysates and fractionated successively on butyl-Sepharose, Q-Sepharose (and Ni-Sepharose when applicable), and finally by dialysis against PBS. Mal-P1 was purified by amylose affinity chromatography (New England Biolabs, Beverly, MA).
- 25 SDS-PAGE analysis of purified hsp65-P1 revealed a major species at 67.5kDa, which was shown to be hsp65-P1 by Western analysis, using anti-mycobacterial hsp65 specific antibody (StressGen, Victoria, Canada), and by electrospray mass spectrometry (M.I.T. Biopolymer Laboratory). Mal-P1 was also subjected to amino acid analysis and SDS-PAGE to confirm molecular weight  
30 (48.1kDa) and purity. P1 and SYRGL peptides were synthesized by the MIT Biopolymers Laboratory. Protein concentrations were estimated by bicinchoninic

acid or amino acid analyses and were expressed in molar terms to facilitate comparisons between proteins and polypeptides of differing molecular masses.

- Endotoxin concentrations of recombinant protein preparations were determined by the Limulus assay, using reagents and conditions according to Associates of Cape  
5 Cod (Falmouth, MA). Peptide concentrations were estimated by W/V or based on amino acid analyses.

#### Antibodies and flow cytometry

- Flow Cytometry was carried out on a FACSCaliber, using CellQuest software (Becton Dickinson, Franklin Lakes, NJ). Unlabeled or FITC-, PE-,  
10 allophycocyanin- or biotin-labeled antibodies against CD69, CD4, CD8, CD11c, CD11b, GR.1, B7.2, B220 or MCH class I (H-2<sup>b</sup>), as well as secondary antibodies and streptavidin labeled with allophycocyanin, or PE, were obtained from Pharmingen (San Diego, CA). 1B2, a clonotypic antibody that recognized 2C TCR (Kranz, D., *et al.*, *Proc. Natl. Acad. Sci. USA*, 81:573-577 (1984)), was purified  
15 from the 1B2 hybridoma and biotinylated using biotinamidocaproate N-hydroxysuccinimide ester (Sigma, St. Louis, MO). The antibody, Y3, is cross-reactive with MCH class I from H-2<sup>b</sup> (K<sup>b</sup>) and H-2<sup>k</sup> haplotypes. It is affinity purified from culture supernatants from the Y3 hybridoma (obtained from ATCC, Rockville, MD) and labeled with fluorescein using fluorescein isothiocyanate.

- 20 Generation of bone-marrow derived dendritic cells and isolation of antigen presenting cells and naive 2C T cells

- To generate bone-marrow derived dendritic cells from C57BL/6 (or C3H) mice, bone marrow was flushed from the femur and tibia, red blood cells were lysed, and the remaining cells were cultured at 10<sup>6</sup> cells/ml in RPMI 1640 medium  
25 (supplemented with 10% heat-inactivated fetal calf serum, 2mM L-glutamine, 10mM HEPES, 50  $\mu$ M  $\beta$ -mercaptoethanol, 100 U/ml penicillin and 100 $\mu$ g/ml streptomycin) containing 20 ng/ml murine GM-CSF (R&D Systems, Minneapolis, MN). The medium was replaced on days 2 and 4, and on day 6 the cells (immature dendritic cells) were harvested for use.

In vitro assays were performed with purified cell populations unless otherwise noted. Magnetic cell sorting (MACS) was carried out according to the manufacturer's instructions (Miltenyi Biotec, Auburn, CA). Dendritic cells (splenic or bone marrow-derived) were isolated by positive sorting using anti-CD11c antibody (purity ranged from 70-97%). Peritoneal lavage macrophages were purified by treating them with biotinylated antibodies specific for CD11c, GR.1, and B220, followed by washing and incubating them with magnetic microbeads coated with anti-CD4 or anti-CD8 antibodies or with streptavidin and then passing them over a negative sorting column. Macrophage purity was typically >90%. For purification of 2C T cells from 2C/RAG transgenic mice, lymph node and spleen cells were coated with anti-CD8 magnetic beads (an average of 2 beads per cell) and positively sorted as above (purity >93%). The purification procedures did not activate APC or T cells as shown by flow cytometry: APC showed no increase in B7.2, MHC class I, or cell diameter, and T cells showed no CD69 upregulation after 24 hr in culture. There was also no significant <sup>3</sup>H-thymidine incorporation by T cells after 48 hr incubation.

#### Cytolytic T cell assays

Unless otherwise noted, <sup>51</sup>Cr-labeled T2-K<sup>b</sup> cells were used as target cells. They were incubated with effector cells derived from either fusion protein-injected mice or from cultured 2C T cell clones for 4 hr in the presence or absence of SYRGL (1μM). Specific lysis was calculated as follows: [(experimental counts - spontaneous counts) / (total counts - spontaneous counts)] x 100.

To assess the ability of various APC to process hsp65-P1, dendritic cells and macrophages were used as target cells. Each of these cell populations was purified by MACS and then <sup>51</sup>Cr-labeled for 1 hr at 37°C. The labeled cells were then incubated with hsp65-P1 together with the 2C CTL clone (L3.100) at a CTL: target cell (E:T) ratio of 5:1. Assays were performed in triplicate using 96-well round bottom plates and cell supernatants were counted in a γ spectrometer after 4 hr. Specific lysis was calculated as above.

### Transient transfection and antigen processing assays

EL4 cells ( $5 \times 10^6$ ) were electroporated with 15  $\mu$ g of the parent plasmids or plasmids containing the genes for P1 (in VR1055) or hsp65-P1 (in pCneo). 48 hr after transfection, the cells were subjected to centrifugation in Ficoll-Paque (Pharmacia Biotech., Piscataway, NJ) (2200rpm, 20 min) and  $10^6$  live cells were incubated with an equal number of splenocytes from naive 2C/RAG mice. After 18 hr the cells were stained with 1B2, anti-CD69, and anti-CD8 antibodies (labeled with FITC, PE, and allophycocyanin, respectively) and 2C T cells were evaluated for upregulation of CD69 by flow cytometry, gating on propidium iodide-negative, 1B2<sup>+</sup>, CD8<sup>+</sup> cells.

### Naive 2C T cell responses to dendritic cells and macrophages and dendritic cell activation assays

Purified dendritic cells and macrophages were incubated with various concentrations of proteins or peptides in 96-well ( $5 \times 10^4$  cells/well) flat bottom plates for 24 hr at 37°C. The following day an equal number of purified naive 2C T cells were added to each well (final volume: 200  $\mu$ l for the 96-well plates, 600  $\mu$ l for the 48-well plates). After 18 hr., the 48-well plates were separated into i) cell pellets to analyze 2C T cells for expression of the acute activation marker CD69 by flow cytometry, gating on propidium iodide-negative, 1B2<sup>+</sup> CD8<sup>+</sup> cells, and ii) cell supernatants to measure IL-2 secretion (in triplicate, using HT2 cells in a standard bioassay) (Watson, J., *J. Exp. Med.*, 150:1510-1519 (1979)). After 48 hr, the 96-well plates were assayed for IFN- $\gamma$  secretion (using 50 $\mu$ l of cell supernatants and a capture ELISA assay (R&D Systems, Minneapolis, MN), and for T cell proliferation (1 mCi <sup>3</sup>H-thymidine (NEN, Boston, MA) was added per well and 16 hr later the cells were harvested to measure <sup>3</sup>H-thymidine-incorporation). Where indicated, 1B2 Fab fragments were added to naive 2C T cells at a final concentration of 25 $\mu$ g/ml.

Immature bone marrow-derived dendritic cells (day 6 of culture) were purified by magnetic sorting (>95% CD11b<sup>+</sup>CD11c<sup>+</sup>) and incubated ( $2.5 \times 10^5$  cells/well in 96-well round bottomed plates) with various fusion proteins or control proteins. The following day, cells were analyzed by flow cytometry for expression

of B7.2 and MHC class I and class II molecules, gating on propidium iodide-negative, CD11c<sup>+</sup> cells.

## RESULTS

Design and characterization of heat shock fusion protein hsp65-P1

5 As shown in Figs. 5A and 5B, the principal fusion protein used herein contains the polypeptide P1 fused to the C-terminus of hsp65. P1 includes the octapeptide, SYRGL, that behaves, in association with K<sup>b</sup>, as a strong agonist for the TCR on 2C T cells (Sykulev, Y., *et al.*, *Immunity*, 4:565-571 (1996)). The sequences that flank the octapeptide in P1 were chosen because they correspond to  
10 those known to be effectively cleaved intracellularly in two unrelated proteins: ovalbumin (Falk, K., *et al.*, *Eur. J. Immunol.*, 22:1323-1326 (1992)) and  $\alpha$ -ketoglutaraldehyde dehydrogenase (Udaka, K., *et al.*, *Cell*, 69:989-998 (1992), see arrows, Fig. 5A). To determine if the P1 polypeptide, alone or linked as a fusion partner to hsp65, could be cleaved intracellularly to liberate the SYRGL octapeptide,  
15 we transfected plasmids containing sequences for P1 or hsp65-P1 were transfected into EL4 cells (H-2<sup>b</sup>). Because relatively few of the transiently transfected cells were expected to express P1 or hsp65-P1, the transfected cell population was not used in cytolytic assays as targets for 2C CTL. Instead, their ability to stimulate naive 2C T cells were examined. As shown in Fig. 5C, 80-90% of these naive T  
20 cells were stimulated to express the acute activation marker CD69 in response to EL4 cells transfected with either the P1 or hsp65-P1 plasmids, while virtually none of the naive T cells were activated by cells transfected with the empty plasmids (vector, shaded histograms, Fig. 5C). These results indicate that in these transfected cells P1 and hsp65-P1 can be cleaved to release the octapeptide, which is then  
25 presented by K<sup>b</sup>.

C57BL/6 mice produce SYRGL-specific CD8<sup>+</sup> cytolytic T cells in response to hsp65-P1

Before immunizing mice with hsp65-P1, it was first ensured that CD8 T cells that can recognize the SYRGL octapeptide (SEQ ID NO: 4) are present in normal  
30 C57BL/6 (H-2<sup>b</sup>) mice. The mice were therefore injected with SYRGL peptide (SEQ

ID NO: 4) in adjuvant (TiterMaxGold), their spleen cells were maintained in culture for several weeks (see Methods) and subsequently tested in a standard cytotoxicity assay. As shown in Fig. 5D, the cell line's lysis of  $K^{b*}$  target cells (T2- $K^b$ ) was SYRGL (SEQ ID NO: 4)-dependent, indicating the presence in these mice of T cells that can respond to SYRGL- $K^b$  complexes.

To determine if the hsp65-P1 fusion protein could stimulate ("prime") anti-SYRGL CTL in vivo, normal C57BL/6 mice were injected subcutaneously (s.c.) with the fusion protein in saline without added adjuvants. Each mouse received two injections, one wk apart. 7 days after the 2<sup>nd</sup> injection cells from regional lymph nodes and spleen were restimulated in culture with SYRGL (1  $\mu$ M) in the absence of exogenous cytokines, and tested after 6 days for CTL activity in a 4 hr cytolytic assay, using  $^{51}$ -Cr labeled  $K^{b*}$  target cells (T2- $K^b$ ; see Methods). Of 40 injected mice, 35 produced CTL whose lysis of the  $K^{b*}$  target cells was SYRGL-dependent (see Fig. 6A for a representative response). C57BL/6 mice treated in exactly the same way with equimolar amounts of various controls (hsp65, P1, or a mixture of hsp65 and P1, or SYRGL alone), all failed to yield SYRGL-specific CTL (Fig. 6A). As little as 1  $\mu$ g (0.015 nmoles) of hsp65-P1 could elicit an anti-SYRGL CTL response. A control fusion protein, made by fusing the P1 sequence to the C-terminus of another bacterial protein chosen simply for ease of purification (the *E. coli* maltose binding protein), here called Mal-P1, was around 10-100 times less effective in these assays (Fig. 6B) and without any detectable effect in others (Figs. 7, 8A-8C, 9A-9C, 10A-10C). Removal of CD8 T cells by magnetic sorting showed that the cytolytic response to hsp65-P1 was due to CD8 T cells (Fig. 6C). These results demonstrate that hsp65-P1, without added adjuvants, can elicit a CD8 T cell response to the fusion partner.

Dendritic cells and macrophages differ in ability to serve as antigen-presenting cells for hsp65-P1

To identify antigen presenting cells (APC) that mediate in vivo CD8 T cell responses, purified preparations of APC from C57BL/6 mice (dendritic cells from spleen or bone marrow, and macrophages from peritoneal lavage) were tested for ability to present processed hsp65-P1 and serve as target cells in cytolytic assays,

using a well-established SYRGL-K<sup>b</sup> specific CTL clone (L3.100) as effectors. When dendritic cells and macrophages were <sup>51</sup>Cr-labelled and incubated with hsp65-P1 for 4 hr, they were lysed effectively and to about the same extent (Fig. 7). No significant lysis was observed, however, when the control fusion protein Mal-P1 was used in place of hsp65-P1, suggesting that processing of hsp65-P1 by these APC was not due to indiscriminate extracellular proteolysis.

Cytolytic reactions with potent CTL clones, such as L3.100, can be exquisitely sensitive, detecting very few and probably as little as one cognate peptide-MHC complex per target cell (Sykulev, Y., *et al.*, *Immunity*, 4:565-571 (1996)). Therefore, a more discriminating assay in which dendritic cells and macrophages that had been incubated with hsp65-P1 were compared as APC for their ability to stimulate naive 2C T cells was used. As shown in Fig. 8A-8C, when the dendritic cells were incubated with hsp65-P1 overnight and then with naive 2C T cells, the naive T cells were stimulated to: i) express CD69, ii) proliferate, and iii) secrete IL-2 and IFN- $\gamma$ . In contrast, the macrophage preparations stimulated none of these responses. (It may be that activated macrophages would have behaved differently, but we deliberately focused on non-activated macrophages and dendritic cells to stimulate conditions in the immunized animal were deliberately focused upon. The response elicited by dendritic cells could be inhibited by the clonotypic, anti-2C TCR, antibody (1B2; Fig. 8C), indicating that they were mediated by ligation of the 2C TCR. The requirement for the hsp65 moiety in the hsp65-P1 fusion protein is emphasized by the result that naive 2C T cells were stimulated to express CD69 by dendritic cells that had been incubated with hsp65-P1 but not by those that had been incubated with the control fusion protein Mal-P1 (Fig. 8A).

Incubation of dendritic cells with various controls (P1 alone, hsp65 alone, or a mixture of hsp65 + P1) in place of hsp65-P1 did not stimulate 2C T cells to secrete IFN- $\gamma$ . However, of all the controls the P1 peptide was exceptional in that it exhibited some activity; with both dendritic cells and macrophages it stimulated CD69 expression and with dendritic cells, but not with macrophages, it induced proliferation and IL-2 secretion by the naive 2C T cells. It is likely that the P1 peptide itself is subject to proteolysis by these APC, particularly by dendritic cells, but whether extracellularly or in some intracellular compartment is not clear.

Whatever the explanation, it should be noted that the P1 polypeptide did not stimulate CD8 CTL production in vivo under conditions where the hsp65-P1 fusion protein was consistently effective (Fig. 6A). In addition, as is shown later, P1 also failed to activate dendritic cells (see Figs. 10A-10C).

- 5           To examine the difference between dendritic cells and macrophages more closely, these cells were incubated with various concentrations of the fusion proteins and then evaluated their ability to stimulate naive 2C T cells. As shown in Fig. 9A, the naive cells proliferated and produced substantial amounts of IL-2 in response to dendritic cells that had been incubated with concentrations of hsp65-P1 in the 0.1-  
10   .01  $\mu$ M range. In contrast, the responses by naive cells were negligible when macrophages were used in place of dendritic cells or when the Mal-P1 control fusion protein was used at concentrations up to 1  $\mu$ M (Fig. 9A). Together, these data suggest that dendritic cells are more effective than macrophages in processing and presenting the octapeptide from hsp65-P1.

15   Heat shock fusion proteins stimulate dendritic cells directly

- The distinctive ability of hsp65-P1 to stimulate naive 2C (anti-SYRGL) T cells in vitro only in the presence of dendritic cells led to the examination of the effect of hsp65-P1 on dendritic cells directly. As shown in Fig. 10A, when immature bone-marrow derived dendritic cells (day 6 in culture) were incubated  
20   overnight with various concentrations of hsp65-P1 the dendritic cell surface level of an MHC class I molecule ( $K^b$ ) was increased. The extent of the increase depended on the hsp65-P1 concentration, and no increase was seen when hsp65-P1 was replaced by a series of control proteins and peptides (hsp65 alone, P1 alone, SYRGL, Mal-P1, or a monoclonal IgG antibody [anti-2,4,6, trinitrophenyl]).

- 25           Other hsp65 fusion proteins, having various fusion partners (influenza virus nucleoprotein or the E7 subunit of human papilloma virus) also elicited increased expression of  $K^b$  on the dendritic cells (Fig. 10A). It is important to note, however, that unmodified hsp65 ("hsp65 only" in Fig. 10A, 10B) consistently failed to stimulate dendritic cell upregulation of  $K^b$ .



All of the fusion proteins as well as unmodified hsp65 were produced as recombinant proteins in *E. coli* and contained trace levels of endotoxin (lipopolysaccharide, LPS). An endotoxin standard by itself evoked a weak response at the highest concentration tested (5 EU/ml, Fig. 10B). Because of mol. wt. heterogeneity of LPS, conversion of endotoxin units into LPS weight and mole units is highly approximate. But, if one EU corresponds to about 5 ng LPS, and the "average" mol. wt. of LPS is taken to be approximately 10,000, LPS would appear to be somewhat more effective than hsp65 fusion proteins in activating dendritic cells. Nevertheless, the effects of the fusion proteins seemed clearly not to be due to endotoxin contaminants, because when hsp65-P1, hsp65, or Mal-P1 were each added in amounts that resulted in addition of equivalent EU units to the dendritic cells, increased expression of K<sup>b</sup> was elicited only by hsp65-P1. Moreover, when the data from Fig. 10A were plotted against the EU concentrations attributable to the controls and fusion proteins, it was evident that each of the four hsp65 fusion protein preparations, but none of the controls, stimulated increased expression of MHC class I protein. Finally, all the hsp65 fusion proteins elicited increases in MHC class I expression on dendritic cells from C3H/HeJ mice, a strain known to be unresponsive to LPS (due to a mutation in the Toll4 receptor) (Poltorak, A., *et al.*, *Science*, 282:2085-2088 (1998)). Taken together, the findings demonstrate that activation of the dendritic cells was due to the hsp65 fusion proteins, not to endotoxin contaminants. Besides stimulating the dendritic cells (bone marrow derived and maintained in culture with GM-CSF for 6 days) to express increased levels of MHC class I, the hsp fusion proteins stimulated increased expression of MHC class II and B7.2 (CD86) (the Table); the level of CD40 was, however, only marginally affected. Native hsp65 did not affect expression of MHC class II or B7.2, just as it failed to affect levels of MHC class I.

#### Table

Heat shock fusion proteins stimulate increased expression of MHC and costimulatory (B7.2) molecules on dendritic cells

	Nothing	unmodified hsp65	P1 peptide	hsp65-NP	hsp65-P1
MHC Class I	100	105	96	257	151
MHC Class II	63	67	55	279	90
B7.2	60	54	47	129	81
CD40	45	45	47	76	51

- 5 Dendritic cells from bone marrow of C3H/HeJ mice were incubated for 18 hrs with  $1.5 \times 10^{-6}$  M of various heat shock proteins or the control P1 peptide prior to cell surface staining.

#### Activated dendritic cells in vivo

- 10 That the dendritic cell changes could also be elicited in vivo was indicated by the finding that 24 hrs after injecting hsp65-P1 (in saline) subcutaneously into mice, myeloid dendritic cells (but not lymphoid dendritic cells) from lymph nodes draining the site of injection showed increased expression of K<sup>b</sup> (Fig. 9B).

- To determine if activated DC were especially effective in vivo, normal B6 mice were adoptively transferred with  $2 \times 10^6$  naive 2C cells (from 2C TCR transgenic mice, see Cho, B., *et al.*, *Proc. Natl. Acad. Sci. USA*, 96:2976-2981 (1999)) and the next day the recipients were injected in a hind footpad with  $8 \times 10^5$  dendritic cells. The dendritic cells had been incubated overnight with or without hsp65-NP (to generate activated or nonactivated dendritic cells, respectively), and then incubated for 2 hrs with SYRGL peptide at various concentrations ( $0$ ,  $10^{-6}$ ,  $10^{-7}$ ,  $10^{-8}$ ,  $10^{-9}$  M) and washed just before the cells were injected. 24 hrs later 2C CD8<sup>+</sup> T cells from the draining popliteal lymph nodes were examined for CD69 expression as evidence of having been antigenically stimulated. As shown in Fig. 9C, when the peptide concentration was  $10^{-9}$  M, the activated dendritic cells were considerably more effective than the nonactivated dendritic cells in stimulating the naive 2C T cells to express CD69. When pulsed with the peptide at 10-1000-times higher concentrations activated and nonactivated dendritic cells were about equally
- 15
- 20
- 25

effective, stimulating CD69 responses of the 2C CD8<sup>+</sup> cells at about the level seen in Fig. 9C, bottom panel.

Stimulation of CD8 CTL production in vivo by the hsp65-P1 fusion protein does not require the participation of CD4 T cells

- 5       The ability of the hsp fusion proteins to directly stimulate dendritic cells suggested that CD4 T cells might not be necessary for the CD8 T cell response elicited in vivo by the fusion proteins. To test this possibility, CD4 knockout mice (CD4<sup>-/-</sup>) were immunized using the same regimen as before (Fig. 6A-6C) and their ability to produce SYRGL-specific CTL was assessed. As seen in a representative
- 10       response in Fig. 10C, the CD4<sup>-/-</sup> mice produced CTL in response to hsp65-P1 but not in response to the control Mal-P1. While the cytolytic activity elicited in the CD4<sup>-/-</sup> mice (n=6) was unambiguous, it appeared to be somewhat less than was generally elicited in normal C57BL/6 mice. In other experiments C57/BL6 mice that had been extensively depleted of CD4 cells by repeated injections or an anti-
- 15       CD4 mAb (GK1.5) also responded to the standard immunization protocol with hsp65-P1 about as well as untreated normal mice (data not shown). All of these results show that in stimulating CD8 CTL production in mice hsp65-P1 does not require the participation of CD4 T cells.

#### Discussion

- 20       As shown herein, mycobacterial hsp65 fused to the P1 polypeptide activates dendritic cells and stimulates, in the absence of CD4<sup>+</sup> T cells, the production of CD8<sup>+</sup> CTL that recognize a short peptide derived from P1. The findings extend the number and diversity of hsp fusion proteins that can elicit CD8 T cell responses and suggest a potential mechanism by which the fusion proteins exert their effects in the
- 25       absence of added adjuvants, a prominent feature of the in vivo responses to all hsp fusion proteins. Generally, where CD4 T cell help and adjuvants are required for CD8 T cell responses, it is likely that they function by activating dendritic cells (Bennett, S., *et al.*, *Eur. J. Immunol.*, *Nature*, 393:478-480 (1998); Ridge, J., *et al.*, *Nature*, 393:474-478 (1998) and Schoenberger, S., *et al.*, *Nature*, 393:480-483
- 30       (1998)). It is reasonable to expect that the capacity of heat shock fusion proteins to

directly activate dendritic cells accounts for their ability to bypass the requirements for CD4 T cells and added adjuvants.

HSP fusion proteins activate dendritic cells directly

Using CTL to detect polypeptide processing by APC, previous studies  
5 pointed to macrophages, or equally to macrophage and dendritic cells, as being responsible for processing protein immunogens that elicit CD8 T cell responses (Kovacsovics-Bankowski, M., *et al.*, *Science*, 267:243-245 (1995); Rock, K., *Today*, 17:131-137 (1996); Suto, R. and Srivastava, P.K., *Science*, 269:1585-1588 (1995)). As shown herein, when macrophages and dendritic cells were incubated with hsp65-  
10 P1 they become equally susceptible to lysis by peptide-specific CTL in a standard 4 hr cytolytic assays, indicating that both types of APC could generate small peptides from the hsp fusion protein and load them on the MHC class I molecules. However, when these cells were evaluated for their ability to stimulate naive CD8 T cells to proliferate and produce IL-2 and IFN- $\gamma$ , the dendritic cells, but not the macrophages,  
15 proved to be effective. A step towards understanding this difference comes from the present finding that hsp65-P1, as well as each of the other hsp65 fusion proteins tested, is capable of directly stimulating dendritic cells to increase their surface expression of MHC class I and II and costimulatory (B7.2) molecules.

Dendritic cells infected with mycobacteria, including BCG, or streptococci,  
20 or Leishmania have been shown to upregulate MHC and costimulatory molecules B7.1 and B7.2 and, in addition, to secrete IL-12 (Demangel, C., *et al.*, *Eur. J. Immunol.*, 29:1972-1979 (1999); Henderson, R., *et al.*, *J. Immunol.*, 159:635-643 (1997); Konecny, P., *et al.*, *Eur. J. Immunol.*, 29:1803-1811 (1999); Rescigno, M., *et al.*, *Proc. Natl. Acad. Sci. USA*, 95:5229-5234 (1998)). It may be that microbial cell  
25 hsp molecules are responsible for these effects. If so, the findings described herein (of a difference between hsp65 fusion proteins and unmodified hsp65) indicate that upregulation of these activation molecules are due to the hsp in a modified form, resembling perhaps the hsp65 fusion proteins studied here, rather than naive hsp molecules.

30 Dendritic cells infected with certain viruses, e.g., influenza virus (Ridge, J., *et al.*, *Nature*, 393:474-478 (1998)), likewise become activated. However, the hsp

fusion proteins appear, so far, to be the only soluble immunogenic proteins that directly activate dendritic cells, in vitro and in vivo, to upregulate expression of MHC and costimulatory molecules. The experimental system described herein is useful for investigating the pathways by which hsp fusion proteins are processed and presented by dendritic cells and the mechanisms by which MHC and costimulatory molecules are up-regulated.

Hsp fusion protein stimulation of CD8 T cell production does not depend upon CD4 T cells.

Prior to the present study one way to account for the ability of hsp fusion proteins to stimulate CD8 T cell production was to invoke a key role for CD4 T cells. Thus, a vigorous CD4 T cell response to peptides from the hsp moiety could activate dendritic cells and amplify an otherwise marginal CD8 T cell response to peptides from the fusion partner (Bennett, S., *et al. Nature*, 393:478-480 (1998); Ridge, J., *et al., Nature*, 393:474-478 (1998); Schoenberger, S., *et al., Nature*, 393:480-483 (1998)). This possibility is supported by older evidence that hsp65 can serve as an effective carrier molecule in the classic sense: i.e., when chemically coupled to nonimmunogenic hapten-like molecules (polysaccharides, a malarial peptide) the conjugates elicited IgG antibodies to the adducts in responses that were presumably T-cell dependent (Barrios, C., *et al., Eur. J. Immunol.*, 22:1365-1372 (1992)). This mechanism is clearly not essential, because CD4<sup>-</sup> mice injected with hsp65-P1 produced cytolytic CD8 T cells to the fusion partner's peptide. Nevertheless, it is entirely possible that in normal animals the response may be enhanced by CD4 T cells specific for peptides derived from the hsp moiety.

Previous efforts to determine whether CD4 T cells are essential for CD8 T cell responses to various immunogens and immunization strategies have yielded diverse results. With some epitopes, e.g., minor histocompatibility antigens, CD8 T cell responses could not be elicited in CD4<sup>-</sup> mice (DiRosa, F. and Matzinger, P., *J. Exp. Med.*, 183:2153-2163 (1996)), but with more potent immunogens, (e.g., lymphocytic choriomeningitis virus or a murine herpes virus), or high doses of particulate antigens, CD8 CTL responses in CD4<sup>-</sup> mice were virtually the same as in normal mice (Rahemtulla, A., *et al., Nature*, 353:180-184 (1991); Rock, K. and

Clark, K., *J. Immunol.*, 156:3721-3726 (1996); Stevenson, P., *et al.*, *Proc. Natl. Acad. Sci. USA*, 95:15565-15570 (1998)). That CD4 T cells are not required for the CD8 T cell response to hsp65-P1 indicates that hsp fusion proteins are relatively potent immunogens for CD8 T cells.

5 The hsp moiety in hsp fusion proteins

In the several hsp fusion proteins examined here the only common element is hsp65. The question arises as to how the hsp moiety can directly activate dendritic cells (and thereby elicit CD8 CTL production), regardless of wide variations in length and sequence of the fusion partners. It is particularly notable, in contrast, that  
10 unmodified ("native") hsp65 lacks this critical activity. It may be that in the fusion proteins the hsp moiety adopts a particular conformation or displays a linear sequence or peptide motif or pattern that is i) necessary for eliciting the dendritic cell response, ii) retained despite wide variations in the fusion partner sequences, and iii) absent or masked in unmodified ("native") hsp65.

15 The intensity of current interest in CD8 vaccines for HIV-1 and other persistent intracellular pathogens, as well as for cancer cells, is reflected in recent studies of diverse genetic vaccines and of several bacterial toxins fused to antigenic peptides or polypeptides as stimulators of CD8 CTL production. For example, nonapeptide sequences inserted into a truncated subunit of anthrax toxin or pertussis  
20 toxin, could elicit CD8 CTL in vivo (Ballard, J., *et al.*, *Proc. Natl. Acad. Sci. USA*, 93:12531-12534 (1996) and render target cells susceptible to lysis by cognate CD8 CTL in vitro (Goletz, T., *et al.*, *Proc. Natl. Acad. Sci. USA*, 94:12059-12064 (1997); Carbonetti, N., *et al.*, *Infect. Immun.*, 67:602-607 (1999)). These and other bacterial toxins have evidently acquired through evolution the capacity to cross mammalian  
25 cell membranes and gain access to the cell cytosol, where they exert their lethal effects. While the judicious linkage of small peptides allows these toxin subunits to retain their ability to traverse membranes, the need to preserve this special property may limit the size and sequence diversity of the fusion elements that can be accommodated. For the hsp fusion proteins, in contrast, there appear so far to be no  
30 constraints to their effectiveness as CD8 immunogens by the length or sequence of the fusion partners. Because large fusion partners, e.g., the equivalent of a typical

protein domain, are likely to encompass many potential epitopes for diverse MHC class I molecules, the hsp fusion proteins as a class are candidate vaccines for use with populations of MHC-disparate individuals.

While this invention has been particularly shown and described with  
5 references to preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the scope of the invention encompassed by the appended claims.

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## CLAIMS

What is claimed is:

1. A method of inducing an immune response that includes a CD8<sup>+</sup> cytotoxic T lymphocyte (CTL) response to a molecule in an individual, the method comprising  
5 administering to the individual the molecule joined to a heat shock protein or the molecule joined to an adenosinetriphosphate (ATP) binding domain of a heat shock protein or a portion thereof.
2. The method of claim 1, wherein the individual has a deficiency of CD4<sup>+</sup> T cells.
- 10 3. The method of claim 1, wherein the heat shock protein is fused to the molecule.
4. The method of claim 1, wherein the ATP binding domain is fused to the molecule.
5. The method of claim 1, wherein the heat shock protein is covalently bonded or chemically conjugated to the molecule.
- 15 6. The method of claim 1, wherein the ATP binding domain, or the portion thereof, is covalently bonded or chemically conjugated to the molecule.
7. The method of claim 1, wherein the molecule is a protein or glycoprotein.
8. The method of claim 1, wherein the molecule is a carbohydrate or lipid.
9. The method of claim 1, wherein the molecule is a bacterial or viral antigen.
- 20 10. The method of claim 10, wherein the viral antigen is an antigen of the human immunodeficiency virus.



11. The method of claim 1, wherein the molecule is a parasitic antigen.
12. The method of claim 1, wherein the molecule is a cancer cell-associated antigen.
13. The method of claim 1, wherein the heat shock protein, the ATP binding domain of the heat shock protein, or the portion thereof, is a mycobacterial protein.
- 5 14. The method of claim 13, wherein the mycobacterial protein is an *M. leprae*, *M. bovis*, or *M. tuberculosis* protein.
15. The method of claim 1, wherein the heat shock protein, the ATP binding domain of the heat shock protein, or the portion thereof, is hsp65, hsp70, or hsp90.
16. The method of claim 1, wherein the heat shock protein, the ATP binding  
10 domain of the heat shock protein, or the portion thereof, is a mammalian protein.
17. The method of claim 16, wherein the mammalian protein is a human protein.
18. The method of claim 1, wherein the portion of the ATP binding domain consists of about half of the ATP binding domain.
19. The method of claim 1, wherein the portion of the ATP binding domain is a  
15 portion of a naturally occurring ATP binding domain in which 1-50% of the amino acid residues have been substituted; 10-40% of the amino acid residues have been substituted; or 10-20% of the amino acid residues have been substituted.
20. The method of claim 19, wherein at least half of the substituted amino acid residues are conservative amino acid substitutions.
- 20 21. The method of claim 1, wherein the portion of the ATP binding domain comprises amino acid residues 161-370 of *Mycobacterium tuberculosis* hsp70.

22. The method of claim 2, wherein the individual has an acquired immune deficiency syndrome.
23. A method of inducing a CD4<sup>+</sup>-independent cytotoxic T lymphocyte response to a molecule in an individual, the method comprising administering to the individual a  
5 portion of an ATP binding domain of a heat shock protein joined to the molecule.
24. The method of claim 23, wherein the molecule is a protein, a peptide, a glycoprotein, a carbohydrate, a viral antigen, a fungal antigen, or a parasitic antigen.
25. The method of claim 23, wherein the heat shock protein is an hsp65, hsp70, hsp90, bacterial, mycobacterial, fungal, parasitic, or mammalian heat shock protein.
- 10 26. A composition comprising a heat shock protein, or a portion thereof, joined to a heterologous molecule.
27. The composition of claim 26, wherein the portion of the heat shock protein is a portion of an ATP binding domain of a heat shock protein.
28. The composition of claim 26, wherein the heat shock protein, or the portion  
15 thereof, is fused to the heterologous molecule.
29. The composition of claim 26, wherein the molecule is a protein, peptide, glycoprotein, carbohydrate, viral antigen, fungal antigen, or parasitic antigen.
30. The composition of claim 26, wherein the heat shock protein is a mycobacterial or mammalian heat shock protein.
- 20 31. The composition of claim 30, wherein the mycobacterial heat shock protein is derived from *Mycobacterium tuberculosis*, *Mycobacterium leprae*, or *Mycobacterium bovis*.

32. The composition of claim 27, wherein the portion of the ATP binding domain consists of about half of the ATP binding domain.

33. The composition of claim 26, wherein the portion of the ATP binding domain is a portion of a naturally occurring ATP binding domain in which 1-50% of the amino  
5 acid residues have been substituted; 10-40% of the amino acid residues have been substituted; or 10-20% of the amino acid residues have been substituted.

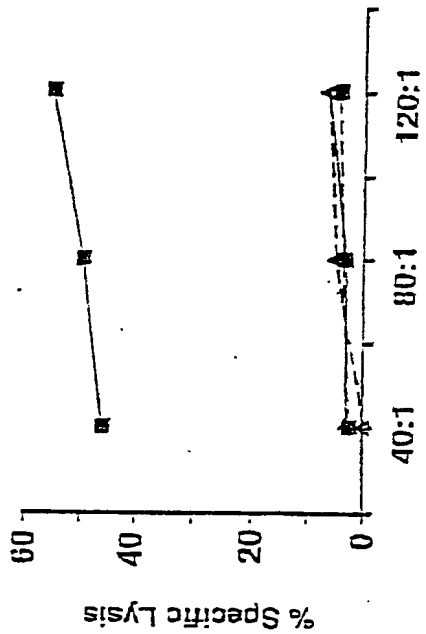
34. The composition of claim 33, wherein at least half of the substituted amino acid residues are conservative amino acid substitutions.

35. The composition of claim 26, wherein the portion of the ATP binding domain  
10 comprises amino acid residues 161-370 of *Mycobacterium tuberculosis* hsp70.

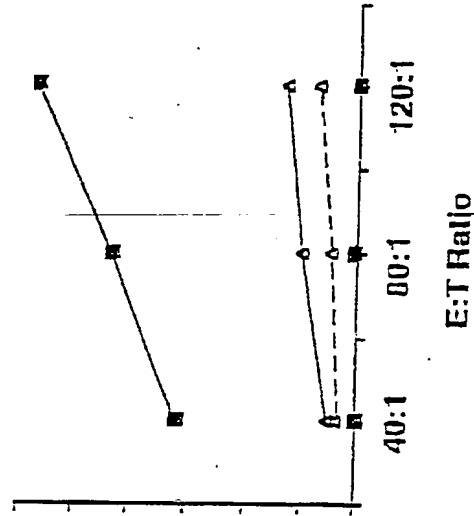
1/12

Figure 1A

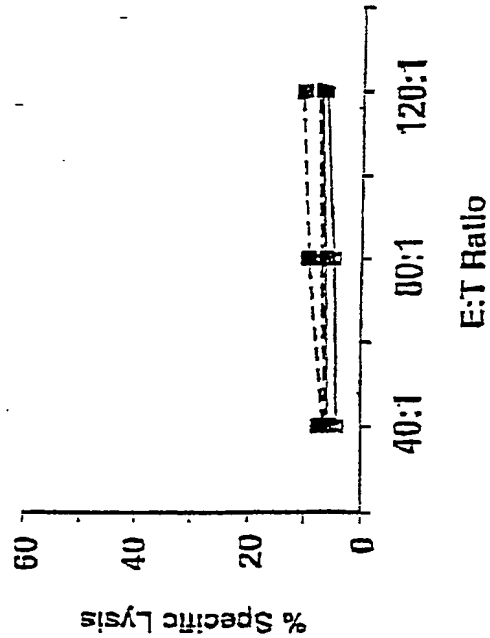
C57BL/6 (Wild Type)



CD4<sup>-/-</sup>



$\beta 2m^{-/-}$



Effector Cells elicited with:

- OVA.TBhsp70
- △ OVA

Target Cells:

- T2-K<sup>b</sup>
- T2-K<sup>b</sup>+SIINFEKL peptide (e.g.,  $1 \times 10^{-7}M$ )

E:T Ratio

Figure 1C

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Figure 2A

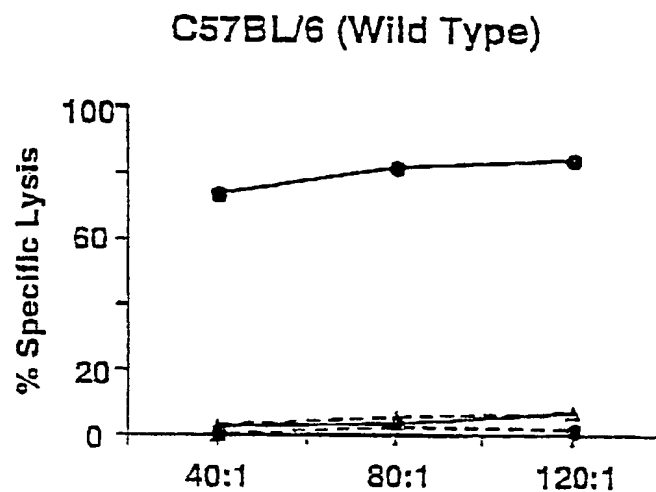
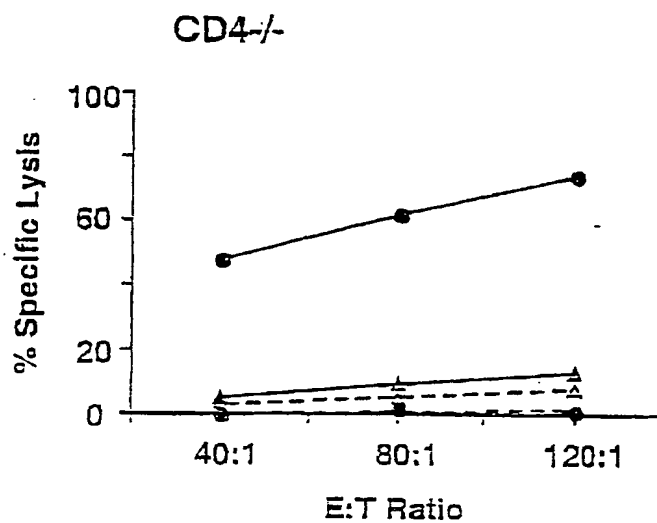


Figure 2B



Effector Cells

elicited with:

● OVA.mhsp70

△ OVA

Target Cells:

--- T2-K<sup>b</sup>— T2-K<sup>b</sup>+SIINFEKL

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## Hsp70 Domains

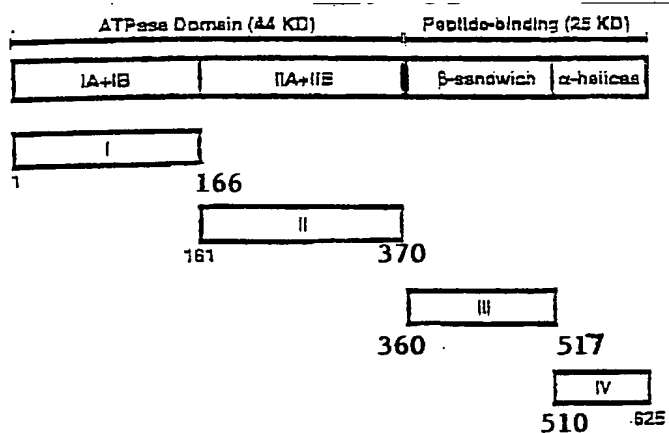


Figure 3

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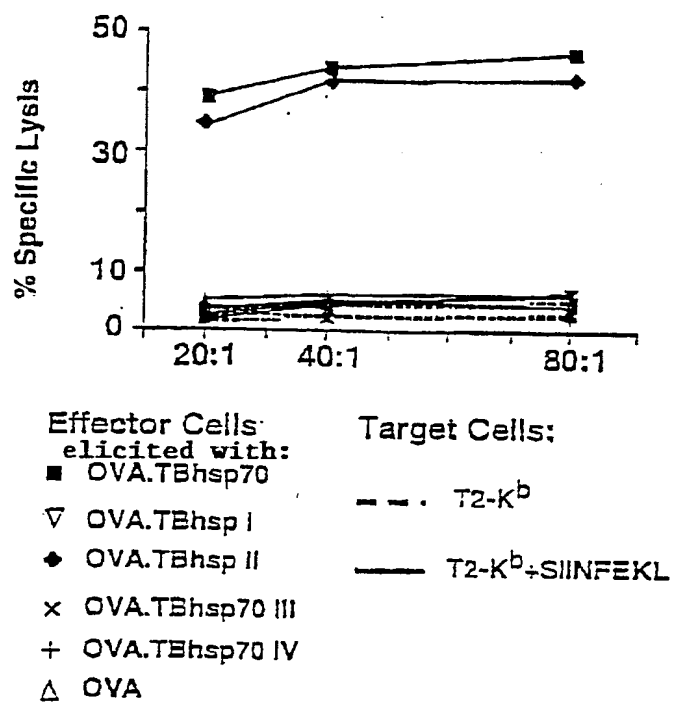
C57BL/6

Figure 4

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IKVSGLEQLESIYRYYGLLLKEAY  
Ova           ↑                   ↑   αKG

Figure 5A



Figure 5B

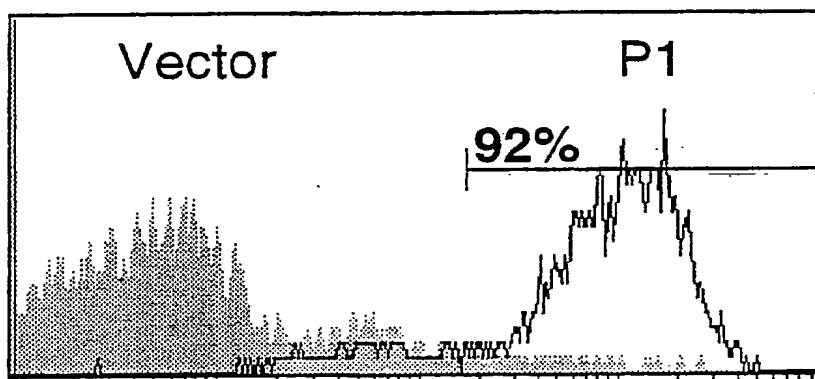
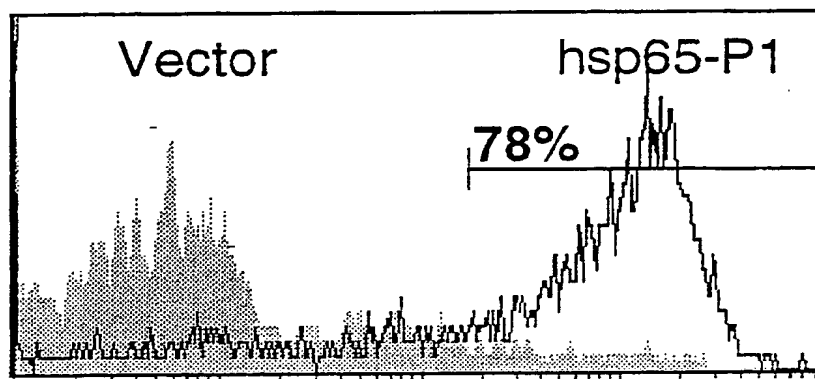
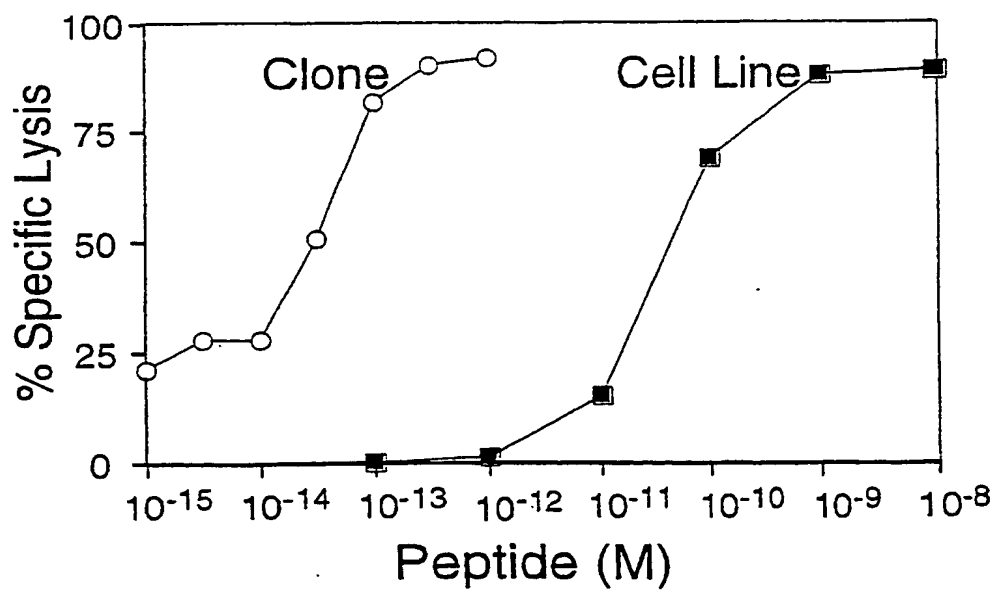


Figure 5C



CD69

Figure 5D





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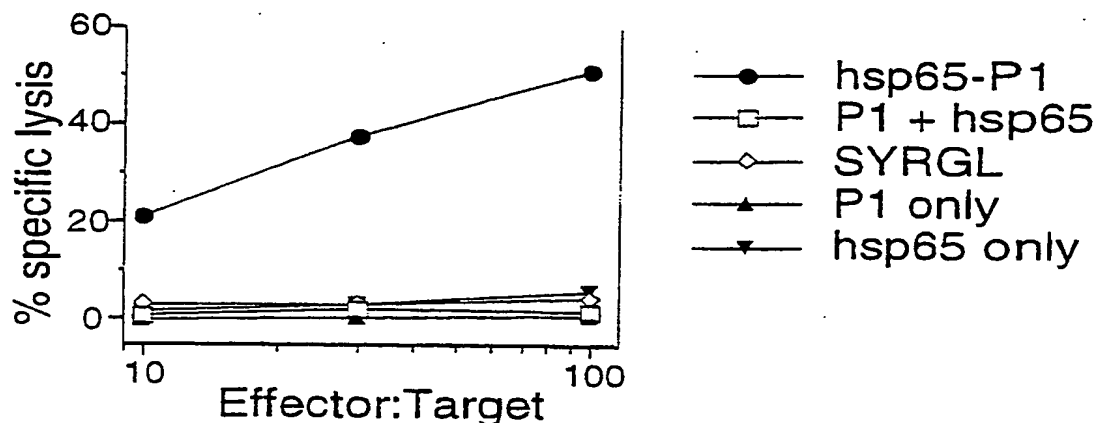


Figure 6A

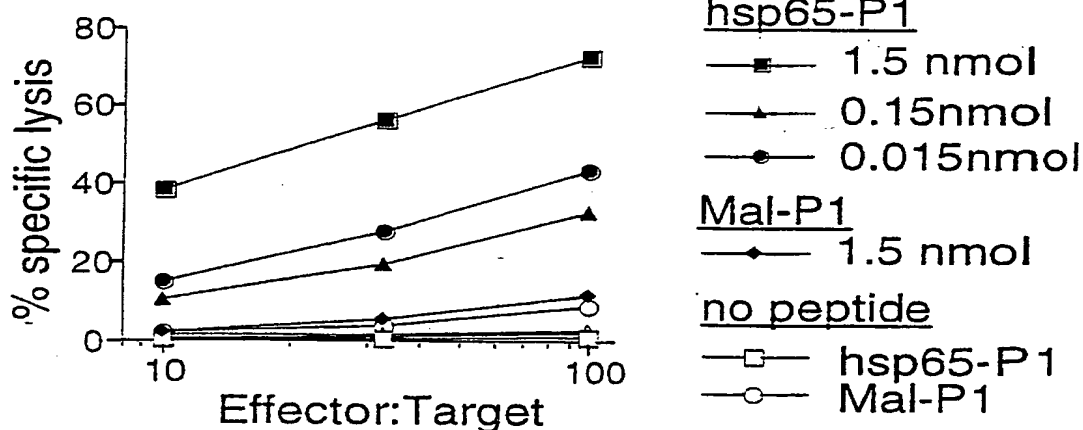


Figure 6B

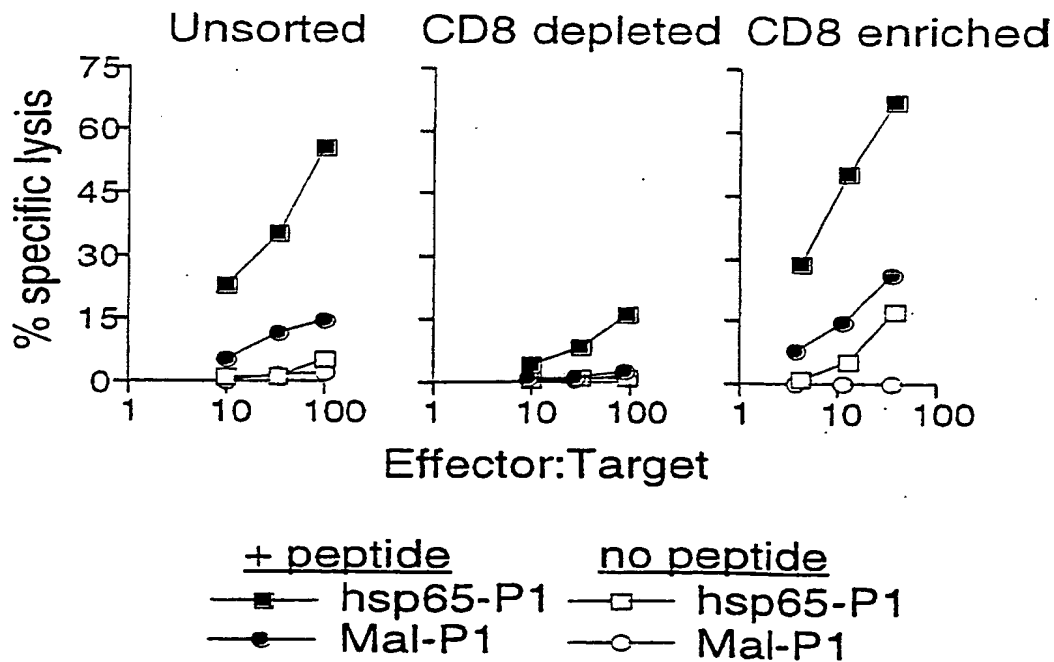


Figure 6C

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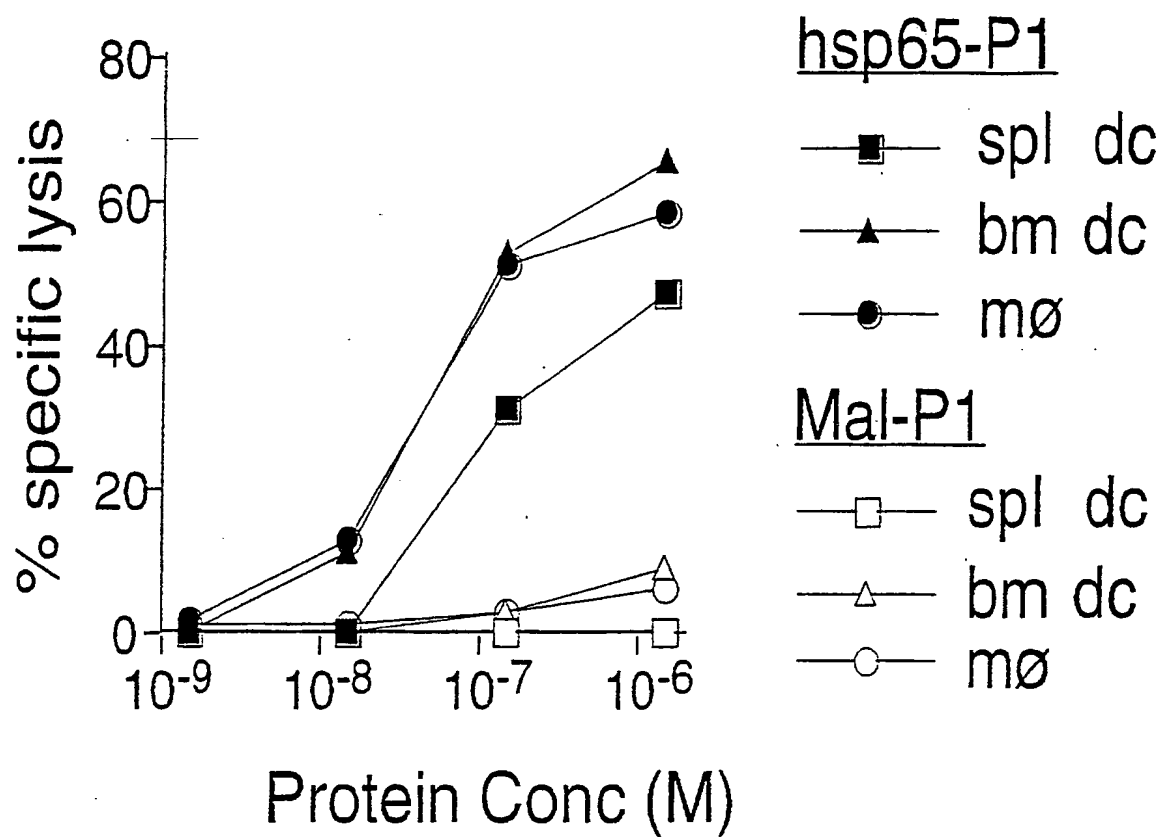


Figure 7

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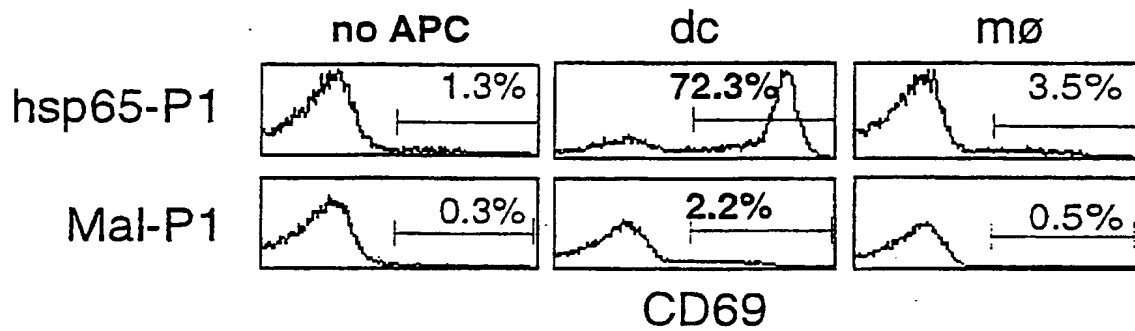


Figure 8A

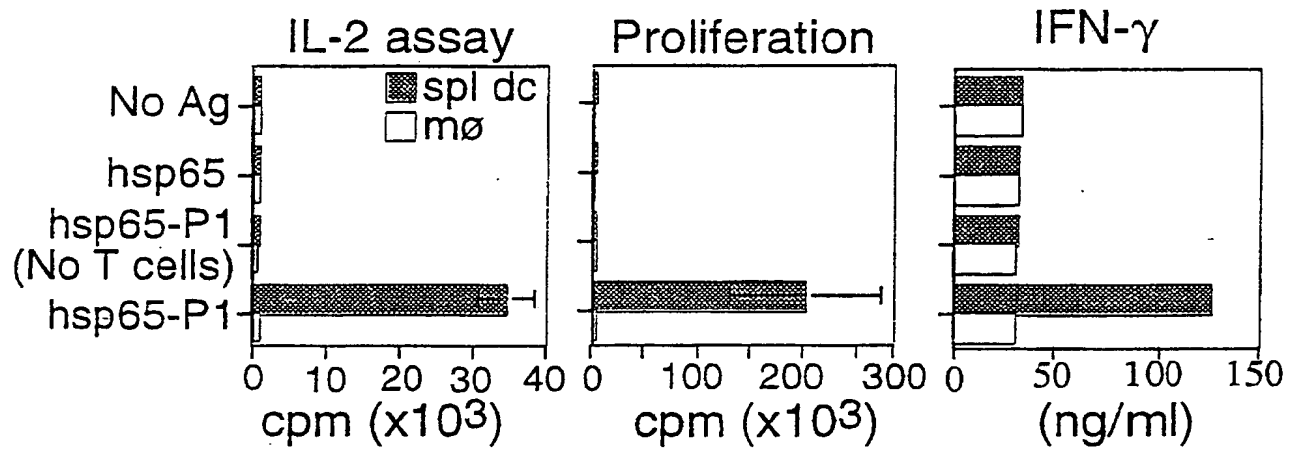


Figure 8B

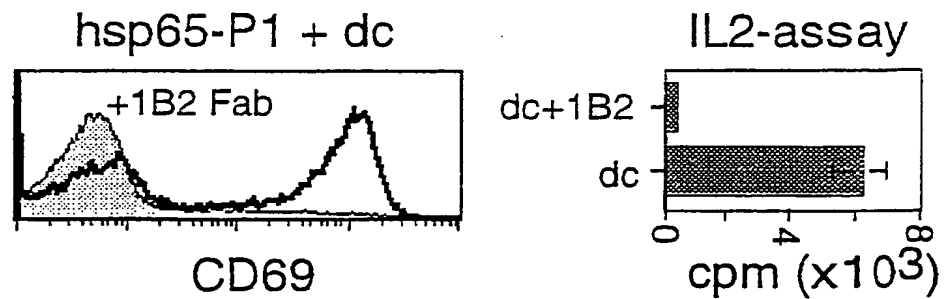


Figure 8C

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Figure 9A

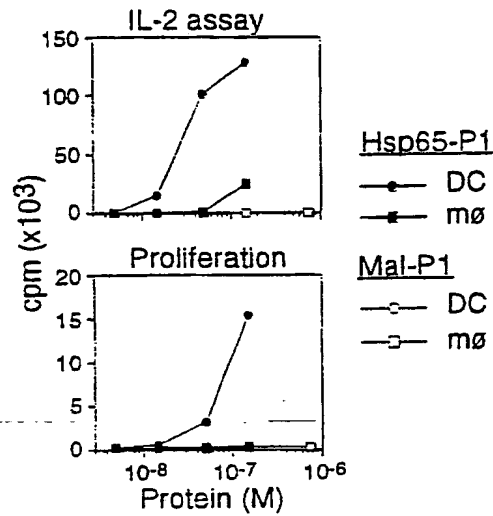


Figure 9B

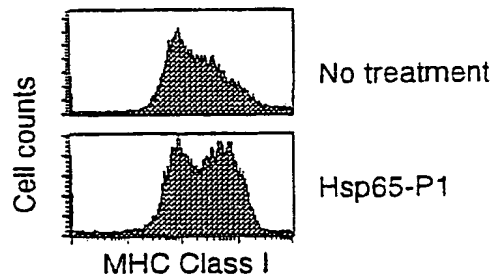
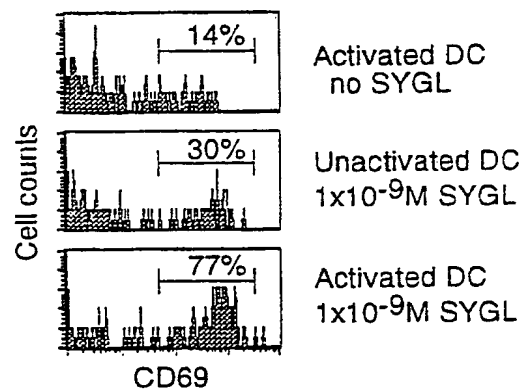


Figure 9C



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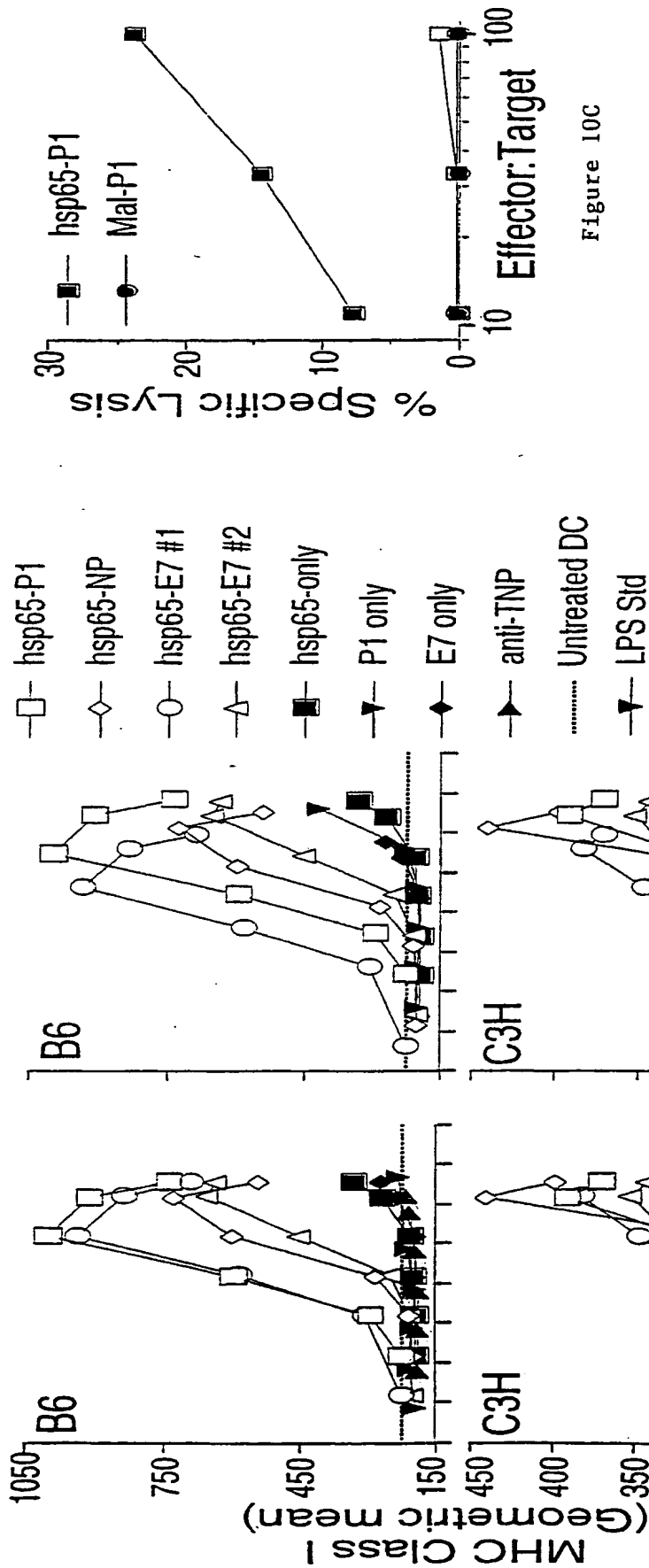


Figure 10C

Figure 10B

Figure 10A

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ATG GCT CGT GCG GTC GGG ATC GAC CTC GGG ACC ACC AAC TCC GTC GTC TCG GTT CTG GAA  
 GGT GGC GAC CCG GTC GTC GTC GCC AAC TCC GAG GGC TCC AGG ACC ACC CCG TCA ATT GTC  
 GCG TTC GCC CGC AAC GGT GAG GTG CTG GTC GGC CAG CCC GCC AAG AAC CAG GCA GTG ACC  
 AAC GTC GAT CGC ACC GTG CGC TCG GTC AAG CGA CAC ATG GGC AGC GAC TGG TCC ATA GAG  
 ATT GAC GGC AAG AAA TAC ACC GCG CCG GAG ATC AGC GCC CGC ATT CTG ATG AAG CTG AAG  
 CGC GAC GCC GAG GCC TAC CTC GGT GAG GAC ATT ACC GAC GCG GTT ATC ACG ACG CCC GCC  
 TAC TTC AAT GAC GCC CAG CGT CAG GCC ACC AAG GAC GCC GGC CAG ATC GCC GGC CTC AAC  
 GTG CTG CCG ATC GTC AAC GAG CCG ACC GCG GCC GCG CTG GCC TAC GGC CTC GAC AAG GGC  
 GAG AAG GAG CAG CGA ATC CTG GTC TTC GAC TTG GGT GGT GGC ACT TTC GAC GTT TCC CTG  
 CTG GAG ATC GGC GAG GGT GTG GTT GAG GTC CGT GCC ACT TCG GGT GAC AAC CAC CTC GGC  
 GGC GAG GAC TGG GAC CAG CGG GTC GTC GAT TGG CTG GTG GAC AAG TTC AAG GGC ACC AGC  
 GGC ATG GAT CTG ACC AAG GAC AAG ATG GCG ATG CAG CGG CTG CGG GAA GCC GCC GAG AAG  
 GCA AAG ATC GAG CTG AGT TCG AGT CAG TCC ACC TCG ATC AAC CTG CCC TAC ATC ACC GTC  
 GAC GCC GAC AAG AAC CCG TTG TTC TTA GAC GAG CAG CTG ACC CGC GCG GAG TTC CAA CGG  
 ATC ACT CAG GAC CTG CTG GAC CGC ACT CGC AAG CCG TTC CAG TCG GTG ATC GCT GAC ACC  
 GGC ATT TCG GTG TCG GAG ATC GAT CAC GTT GTG CTC GTG GGT GGT TCG ACC CGG ATG CCC  
 GCG GTG ACC GAT CTG GTC AAG GAA CTC ACC GGC GGC AAG GAA CCC AAC AAG GGC GTC AAC  
 CCC GAT GAG GTT GTC GCG GTG GGA GCC GCT CTG CAG GCC GGC GTC CTC AAG GGC GAG GTG  
 AAA GAC GTT CTG CTG CTT GAT GTT ACC CCG CTG AGC CTG GGT ATC GAG ACC AAG GGC GGG  
 GTG ATG ACC AGG CTC ATC GAG CGC AAC ACC ACG ATC CCC ACC AAG CGG TCG GAG ACT TTC  
 ACC ACC GCC GAC GAC AAC CAA CCG TCG GTG CAG ATC CAG GTC TAT CAG GGG GAG CGT GAG

Figure 11

GAG AAG GAG CAG CGA ATC CTG GTC TTC GAC TTG GGT GGT GGC ACT TTC GAC GTT TCC CTG  
 CTG GAG ATC GGC GAG GGT GTG GTT GAG GTC CGT GCC ACT TCG GGT GAC AAC CAC CTC GGC  
 GGC GAC GAC TGG GAC CAG CGG GTC GTC GAT TGG CTG GTG GAC AAG TTC AAG GGC ACC AGC  
 GGC ATG GAT CTG ACC AAG GAC AAG ATG GCG ATG CAG CGG CTG CGG GAA GCC GCC GAG AAG  
 GCA AAG ATC GAG CTG AGT TCG AGT CAG TCC ACC TCG ATC AAC CTG CCC TAC ATC ACC GTC  
 GAC GCC GAC AAG AAC CCG TTG TTC TTA GAC GAG CAG CTG ACC CGC GCG GAG TTC CAA CGG  
 ATC ACT CAG GAC CTG CTG GAC CGC ACT CGC AAG CCG TTC CAG TCG GTG ATC GCT GAC ACC  
 GGC ATT TCG GTG TCG GAG ATC GAT CAC GTT GTG CTC GTG GGT GGT TCG ACC CGG ATG CCC  
 GCG GTG ACC GAT CTG GTC AAG GAA CTC ACC GGC GGC AAG GAA CCC AAC AAG GGC GTC AAC  
 CCC GAT GAG GTT GTC GCG GTG GGA GCC GCT CTG CAG GCC GGC GTC CTC AAG GGC GAG GTG  
 AAA GAC GTT CTG CTG CTT GAT GTT ACC CCG

Figure 12

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ATG GCC AAG AAC ACG GCG ATC GGC ATC GAC CTG GGC ACC ACC TAC TCG TGC GTG GGC GTG  
 TTC CAG CAC GGC AAG GTG GAG ATC ATC GCC AAC GAC CAG GGC AAC CGC ACG ACC CCC AGC  
 TAC GTG GCC TTC ACC GAC ACC GAG CGC CTC ATC GGG GAC GCC GCC AAG AAC CAG GTG GCG  
 CTG AAC CCG CAG AAC ACC GTG TTC GAC GCG AAG CCG CTG ATC GGC CGC AAG TTC GGC GAT  
 GCG GTG GTG CAG TCC GAC ATG AAG CAC TGG CCC TTC CAG GTG GTG AAC GAC GGC GAC AAG  
 CCC AAG GTG CAG GTG AAC TAC AAG GGC GAG AGC CCG TCG TTC CCG GAG GAG ATC TCG  
 TCC ATG GTG CTG ACG AAG ATG AAG GAG ATC GCT GAG GCG TAC CTG GGC CAC CCG GTG ACC  
 AAC GCG GTG ATC ACG GTG CCC GCC TAC TTC AAC GAC TCT CAG CCG CAG GCC ACC AAG GAC  
 GCG GGC GTG ATC GCC GGT CTA AAC GTG CTG CCG ATC ATC AAC GAG CCC ACG GCG GCC GCC  
 ATC GCC TAC GGG CTG GAC CCG ACC GGC AAG GGC GAG CCG AAC GTG CTC ATC TTC GAC CTG  
 GGG GGC GGC ACG TTC GAC GTG TCC ATC CTG ACG ATC GAC GAC GGC ATC TTC GAG GTG AAG  
 GCC ACG GCG GGC GAC ACG CAC CTG GGA GGG GAG GAC TTC GAC AAC CCG CTG GTG AGC CAC  
 TTC GTG GAG GAG TTC AAG AGG AAG CAC AAG AAG GAC ATC AGC CAG AAC AAG CCG GCG GTG  
 CCG CCG CTG CCG ACG GCG TGT GAG AGG GCC AAG AGG ACG CTG TCG TCC AGC ACC CAG GCC  
 AGC CTG GAG ATC GAC TCT CTG TTC GAG GGC ATC GAC TTC TAC ACA TCC ATC ACG CCG GCG  
 CCG TTC GAA GAG CTG TGC TCG GAC CTG TTC CCG GGG ACG CTG GAG CCC GTG GAG AAG GCG  
 CTG CCG GAC GCC AAG ATG GAC AAG GCC CAG ATC CAC GAC CTG GTG CTG GTG GGC GGC TCG  
 ACG CCG ATC CCC AAG GTG CAG AAG CTG CTG CAG GAC TTC TTC AAC GGG CCG GAC CTG AAC  
 AAG AGC ATC AAC CCG GAC GAG GCG GTG GCC TAC GGG GCG GCG GTG CAG GCG GCC ATC CTG  
 ATG GGG GAC AAG TCG GAG AAC GTG CAG GAC CTG CTG CTG CTG GAG GTG CCG CCC CTG TCG  
 CTG GGC CTG GAG ACT GCG GGC GGC GTG ATG ACG GCG CTC ATC AAG GCG AAC TCC ACC ATC  
 CCC ACC AAG CAG ACG CAG ACC TTC ACC ACC TAC TCG GAC AAC CAG CCC GGG GTG CTG ATC

Figure 13A

CAG GTG TAC GAG GGC GAG AGG GCC ATG ACG CCG GAC AAC AAC CTG CTG GGG CCG TTC GAG  
 CTG AGC GGC ATC CCG CCG GCG CCC AGG GGC GTC CCG CAG ATC GAG GTG ACC TTC GAC ATC  
 GAC GCC AAC GGC ATC CTG AAC GTC ACG GCC ACC GAC AAG AGC ACC GGC AAG GCC AAC AAG  
 ATC ACC ATC ACC AAC GAC AAG GGC CCG CTG AGC AAG GAG GAG ATC GAG CCG ATG GTG CAG  
 GAG GCC GAG CCG TAC AAG GCC GAG GAC GAG GTG CAG CCG GAC AGG GTG CCG GCC AAG AAC  
 GCG CTC GAG TCC TAT GCC TTC AAC ATG AAG AGC GCC GTG GAG GAC GAG GGT CTC AAG GGC  
 AAG CTC AGC GAG GCT GAC AAG AAG AAG GTC CTG GAC AAG TGC CAG GAG GTC ATC TCC TGG  
 CTG GAC TCC AAC ACG CTG GCC GAC AAG GAG GAG TTC GTG CAC AAG CCG GAG GAG CTG GAG  
 CCG GTG TGC AGC CCC ATC ATC AGT GGG CTG TAC CAG GGT GCG GGT GCT CCT GGG GCT GGG  
 GGC TTC GGG CCG CAG GCG CCG CCG AAA GGA GCC TCT GGC TCA GGA CCC ACC ATC GAG GAG  
 GTG GAT TAG

Figure 13B

GGG GGC GGC ACG TTC GAC GTG TCC ATC CTG ACG ATC GAC GAC GGC ATC TTC GAG GTG AAG  
 GCC ACG GCG GGC GAC ACG CAC CTG GGA GGG GAG GAC TTC GAC AAC CCG CTG GTG AGC CAC  
 TTC GTG GAG GAG TTC AAG AGG AAG CAC AAG AAG GAC ATC AGC CAG AAC AAG CCG GCG GTG  
 CCG CCG CTG CCG ACG GCG TGT GAG AGG GCC AAG AGG ACG CTG TCG TCC AGC ACC CAG GCC  
 AGC CTG GAG ATC GAC TCT CTG TTC GAG GGC ATC GAC TTC TAC ACA TCC ATC ACG CCG GCG  
 CCG TTC GAA GAG CTG TGC TCG GAC CTG TTC CCG GGG ACG CTG GAG CCC GTG GAG AAG GCG  
 CTG CCG GAC GCC AAG ATG GAC AAG GCC CAG ATC CAC GAC CTG GTG CTG GTG GGC GGC TCG  
 ACG CCG ATC CCC AAG GTG CAG AAG CTG CTG CAG GAC TTC TTC AAC GGG CCG GCG GCG ATC CTG  
 AAG AGC ATC AAC CCG GAC GAG GCG GTG GCC TAC GGG GCG GCG GTG CAG GCG GCC ATC CTG  
 ATG GGG GAC AAG TCG GAG AAC GTG CAG GAC CTG CTG CTG CTG GAC GTG GCG CCC

Figure 14

# INTERNATIONAL SEARCH REPORT

national Application No

PCT/US 00/32831

## A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 A61K39/04 A61K39/21 A61K39/00 A61K39/39 A61K47/48  
//C07K19/00,C07K14/35

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 C07K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, MEDLINE, WPI Data, PAJ, BIOSIS, EMBASE, CHEM ABS Data

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 98 35705 A (WHITEHEAD BIOMEDICAL INST ;YOUNG RICHARD A (US)) 20 August 1998 (1998-08-20) page 4, line 19 -page 6, line 7 page 9, line 10 -page 10, line 2 page 28, line 5 -page 29, line 4	1-35
X	SUZUE K ET AL: "ADJUVANT-FREE HSP70 FUSION PROTEIN SYSTEM ELICITS HUMORAL AND CELLULAR IMMUNE RESPONSES TO HIV-1" JOURNAL OF IMMUNOLOGY,US,THE WILLIAMS AND WILKINS CO. BALTIMORE, vol. 156, 1996, pages 873-879, XP002070468 ISSN: 0022-1767 cited in the application abstract page 875, right-hand column	1-4,7, 9-11,14, 15,22, 26,28-31

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

### \* Special categories of cited documents:

\*A\* document defining the general state of the art which is not considered to be of particular relevance

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\*L\* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

\*O\* document referring to an oral disclosure, use, exhibition or other means

\*P\* document published prior to the international filing date but later than the priority date claimed

\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

\*X\* document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

\*Y\* document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

\*G\* document member of the same patent family

Date of the actual completion of the international search

26 March 2001

Date of mailing of the international search report

05.04.01

Name and mailing address of the ISA

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Fax (+31-70) 340-3016

Authorized officer

von Ballmoos, P



# INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 00/32831

**C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT**

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SUZUE K ET AL: "HEAT SHOCK FUSION PROTEINS AS VEHICLES FOR ANTIGEN DELIVERY INTO THE MAJOR HISTOCOMPATIBILITY COMPLEX CLASS I PRESENTATION PATHWAY" PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF USA, US NATIONAL ACADEMY OF SCIENCE, WASHINGTON, vol. 94, 1 November 1997 (1997-11-01), pages 13146-13151, XP002070395 ISSN: 0027-8424 cited in the application abstract section "discussion"	1,3,7, 12-15, 26,28-31
X	WO 99 07860 A (CHU RANDALL; MIZZEN LEE (CA); STRESSGEN BIOTECHNOLOGIES CORP (CA)) 18 February 1999 (1999-02-18) page 15, line 29 - line 30 abstract example 9	1,3,5,7, 9,12-15, 26,28-31
X	WO 97 26910 A (MAX DELBRUECK CENTRUM ; BENNDORF RAINER (DE); MILLECK JUERGEN (DE);) 31 July 1997 (1997-07-31) claims 1-15	1,3,5,7, 12-15, 26,28-31
P,X	HUANG Q ET AL: "In vivo cytotoxic T lymphocyte elicitation by mycobacterial heat shock protein 70 fusion proteins maps to a discrete domain and is CD4(+) T cell independent." JOURNAL OF EXPERIMENTAL MEDICINE, (2000 JAN 17) 191 (2) 403-8. , XP000974127 the whole document	1-35

# INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 00/32831

## Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☒ Claims Nos.:  
because they relate to subject matter not required to be searched by this Authority, namely:  
  
Although claims 1-25 are directed to a method of treatment of the human/animal body, the search has been carried out and based on the alleged effects of the compound/composition.
2. ☐ Claims Nos.:  
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3. ☐ Claims Nos.:  
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

## Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

# INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 00/32831

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